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METASOMATIC ORIGIN OF THE ADIRONDACK MAGNETITE DEPOSITS.

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ABSTRACT.

The study of several hundred thin sections from most of the magnetite mines and prospects in the Adirondacks over a period of twenty years, has convinced me that the ore is in large measure due to high temperature metasomatic replacement. James F. Kemp in 1897 suggested this mode of origin. But his early paper has been forgotten or ignored by most of the later investigators, although both Colony and I have called attention to it. As the ore itself is largely the result of replacement, the method of attack was obviously through a study of the wall rocks. This shows that a series of overlapping processes, involving differentiation, assimilation, crystallization, contact action, deuteric, metasomatic, pegmatitic and hydrothermal introductions, took place. Gallagher has proved that most of these processes operated at Lyon Mountain. This paper extends these into a generalization applicable to most of the magnetite deposits of the Adirondacks.

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INTRODUCTION.

THIS paper is the result of a continuation of petrographic studies of slides and polished blocks from many mines and prospects in the Adirondacks that resulted in a preliminary publication in 1925.[1] Since that time I have been convinced that high temperature metasomatic replacement was one of the chief processes forming these ores. Consequently, Gallagher's[2] impressively thorough study of one of the important mines in the region was a stimulus to reexamine and restate with added details my conclusions, which are in large measure in conformity with his.

My studies have led me to generalizations that are applicable, with local modifications, to the deposits of which I possess thin sections and have acquaintance.

Gallagher[3] gives me the credit for the first published recognition of replacement in these deposits.[4] I am confident, however, that Kemp should receive such credit, for in 1897[5] he described those at Port Henry as "contact deposits formed by the influence and stimulus of the . . . [syenitic[6]] intrusion . . . Attendant on . . . cooling and crystallization, the emission of . . . solutions of iron and other compounds transpired, presumably with vapors in some degree, and these circulating along various

[1] Alling, Harold L.: Genesis of the Adirondack magnetites. ECON. GEOL., XX: 335–363, 1925.

[2] Gallagher, David: Origin of the magnetite deposits at Lyon Mountain, New York. New York State Mus. Bull., 311: 1–85, 1937.

[3] Op. cit., p. 10.

[4] Alling, Harold L.: Op. cit., p. 335.

[5] Kemp, J. F.: The geology of the magnetites near Fort Henry, New York, and especially those of Mineville. A. I. M. E., Trans., XXVII: 146–203, 1897 (1898).

[6] "Syenitic" is substituted for Kemp's term "gabbro" to meet the demands of modern nomenclature. This does not affect in any way the significance of his statement.

contacts gave rise to the ore bodies. They must have replaced in large part the wall rocks and have made a place for the iron oxide in this way." Colony[7] remarked that "this is an exceedingly shrewd observation, the significance of which has been overlooked or neglected." Kemp, therefore, emphasized three processes: (*a*) contact action, (*b*) pneumatolytic deposition and (*c*) replacement of the wall rocks.

THE GRENVILLE SERIES.

It is easy to understand the difficulties of the early geologists in determining the nature of the country rock at many localities. They debated the question whether they were igneous or sedimentary in origin. We now know that the ore was derived from igneous sources but that in itself does not prove the wall rock in every case is wholly igneous as well. There is no doubt about the enclosing rock at Lyon Mountain, Mineville, Palmer Hill or at Arnold; they are chiefly granites, but at the old mines near Crown Point the rocks are "banded gneisses and schists that can be classed without reserve in the sedimentary or Grenville series."[8] Even at the localities where granites occur, representatives of these ancient sediments are found. The amount of Grenville may differ from locality to locality but is, I believe, never completely absent. The "grayband"[9] at Lyon Mountain is, I hold, partially replaced Grenville. Representatives of the Grenville became partners in the formation of garnet contact zones in a few localities. It seems likely that the shape of the ore bodies themselves was governed, in part at least, by engulfed blocks of these old folded and faulted rocks.

The common type of sediment in the mines is a hornblende schist. Studies of Grenville stratigraphy in the Eastern Adirondacks[10] have revealed that two formations of hornblende schist

[7] Colony, R. J.: The magnetite iron deposits of Southeastern New York. New York State Mus. Bull., 249–250: 69, 1923.

[8] Newland, D. H.: New York State Mus. Bull., 119: 40, 1908.

[9] This miners' term Gallagher has adopted. This relatively thin "slab" is closely identified with the ore and can be used for tracing the ore in depth. It is a hornblende-plagioclase rock.

[10] Alling, Harold L.: Geol. Soc. Am. Bull., 38: 795–804, 1927.

aggregating 200 feet, are known. These are plagioclase-hornblende rocks. It is further believed that Grenville marbles pyrometamorphosed by the granites develop into similar rocks, even though Balk [11] does not accept this view. These rocks are also known as paramphibolites. At Hammondville the wall rock appears to me (to others, different interpretations are of course in order) to be a paramphibolite partially replaced by granitic matter producing a hornblende (in part hastingsite)-plagioclase-magnetite rock. This is the Hammondville gneiss of Newland.[12] He says "the question . . . involves the origin of the gneiss, whether this is to be considered a member of the sedimentary series . . . or whether it represents an intrusive. . . ." [13] My suggestion is that it is both; it is a migmatite.

METAGABBRO.

One of the major problems of the Adirondacks is the origin of the amphibolites-metagabbros. Especially in western portions of the mountains relatively long thin bands of a hornblende schist occur embedded in foliated granite. These have no obvious connection with recognized Grenville, consequently many geologists have regarded them as metamorphosed dikes and sills of gabbro or diorite now swamped by the granites. Microscopically these rocks are so similar to hornblende-schists, definitely proved to be members of the Grenville series, that no adequate assistance in distinguishing them is thereby obtained. Both the paramphibolites and the ortho-amphibolites were immersed in granitic melts and accordingly their minerals have been readjusted to equilibrium conditions. The environment being the same, the minerals also are similar.

In spite of their different origins they behave much the same in the field. At magnetite mines both rocks performed a common function. Consequently, it is not a practical necessity to distinguish the two. This is the reason for the common expression "amphibolite (or metagabbro)." It should not cause any

11 Balk, Robert: New York State Mus. Bull., 290: 56, 1932.
12 Newland, D. H.: New York State Mus. Bull., 119: 45–48, 1908.
13 Op. cit., p. 48.

confusion as used here. The scientific problem, however, still remains unsolved.

SEGREGATIONS FROM BASIC SYENITE.

In addition to the theories that the hornblendic rock in the wall rocks, such as at Hammondville and the "grayband" at Lyon Mountain, is either soaked or disrupted fragments of Grenville sediments or included stringers of metagabbro, Balk [14] suggests that much of the amphibolite of the Newcomb quadrangle, and hence by implication of the Adirondacks in general, are lenticular segregations of the syenite. He discards the theory that assimilated inclusions of Grenville marble or other types of the clastic rocks can be transformed into such amphibolites. Not all of the Adirondack geologists follow him, however. We can be reasonably sure that a lenticular segregation of a gabbro within the syenite-granite will by magmatic readjustment be transformed into hornblende-plagioclase rocks with the same mineralogy as Grenville schists or metagabbro. They will have the same general parallelism to the structure of the country rock, and be equally susceptible to metasomatic replacement by iron-rich matters.

STRUCTURE OF THE COUNTRY ROCK.

Gallagher's study confirms the opinion of many geologists that the magnetite ore bodies are conformable with the foliation of the country rock. The discovery of miarolite cavities in the Lyon Mountain mines seems to remove most of the emphasis upon dynamic stress metamorphism after consolidation, and establishes the theory of magmatic flowage as the cause of the foliation. To my mind this is conclusive. But this is not the complete picture. The direction of magmatic flowage was, I hold, in many cases definitely controlled by the baffle plate action of Grenville sediments. Absence of easily recognized clastic rocks in the vicinity of a given mine does not necessarily rule out their former presence because erosion, lit-par-lit injection, magmatic attack, soakings and partial assimilative replacement have either

[14] Op. cit., pp. 56, 84.

removed or disguised them. Both Colony [15] and I [16] have stressed this dependence of the Grenville structure upon the granite. Colony expressed it as an "inherited structure"; my term is "superimposed foliation." Newland [17] recognized this in 1923. He wrote that the ore bands and the foliation of the granitic wall rocks are elongated in the same direction, "an inheritance perhaps of an early defined line of weakness marked out in the old Grenville."

TEXTURAL MINERALOGY OF THE WALL ROCK.

The igneous wall rock is granitic, a member of the often called "syenite series." It is an augite quartz syenite, grading into an augite granite on the one hand, and to a quartz diorite on the other.

Pyroxene.—The pyroxene is emerald green and therefore contains soda in the form of the acmite constituent (minal). Its composition averages: diopside, 70 per cent, acmite, 20 per cent, and hedenbergite, 10 per cent.

The observation that the pyroxene is both early and commonly corroded, strongly suggests that it is a residual mineral derived from early crystallization of the basic magma from which the granite differentiated. In other words, the pyroxene was not in equilibrium with the granitic melt. As seen under the microscope the mineral has been altered to and partially replaced by martite, hematite, and quartz, evidently by magmatic attack. Later pegmatitic and hydrothermal solutions produced calcite and chlorite. Application of the reaction principle would suggest that such a pyroxene could (or would) react with water and additional silica to be transformed into an amphibole and that in turn into a mica. But there is very little amphibole or mica in the wall rock.

Hastingsite.—The country rock contains only a little amphibole which has been called by Gallagher [18] a hastingsite, signifying

[15] Op. cit., pp. 249–250.

[16] Alling, Harold, L., Am. Jour. Sci. (5), VIII: 12–32, 1924. Econ. Geol., XX: p. 342, 1925.

[17] Newland, D. H.: Econ. Geol., XVIII: 295, 1923.

[18] Op. cit., p. 39.

a high percentage of $H_2Mg_7(SiO_3)_8$, the other constituent (minal) is reibeckite. There is, therefore, some similarity between the composition of the pyroxene and this amphibole. It may be that some of the hastingsite has been formed by such a reaction.

There is another view, namely, that this amphibole is foreign to the granite and was acquired through assimilation of either Grenville paramphibolite or metagabbroic ortho-amphibolite. Such a view is supported by the fact that the granitic wall rock is in many places associated with the Grenville. This is definitely established at the Cheever Mine,[19] and the Pilfershire ores near Port Henry. Garnet contact zones occur against Grenville fragments in many mines. Furthermore, graphite has been detected in magnetite-rich wall rocks. Hornblendic schists, proved in the field to be conformable with Grenville marbles, contain hastingsite. Hastingsite is the chief ferromagnesian mineral in the "gray-band"[20] at Lyon Mountain, Mineville, and other localities. I am inclined to accept this theory as the major process in the origin of the hastingsite.

Although elaborate detailed collecting and quantitative measurements of the percentage of hastingsite in granitic wall rock and the distance from Grenville sediments have not been undertaken, my experience would suggest that the amount of this amphibole depends in part upon the nearness to inclusions of Grenville and upon the quantity of Grenville assimilated.

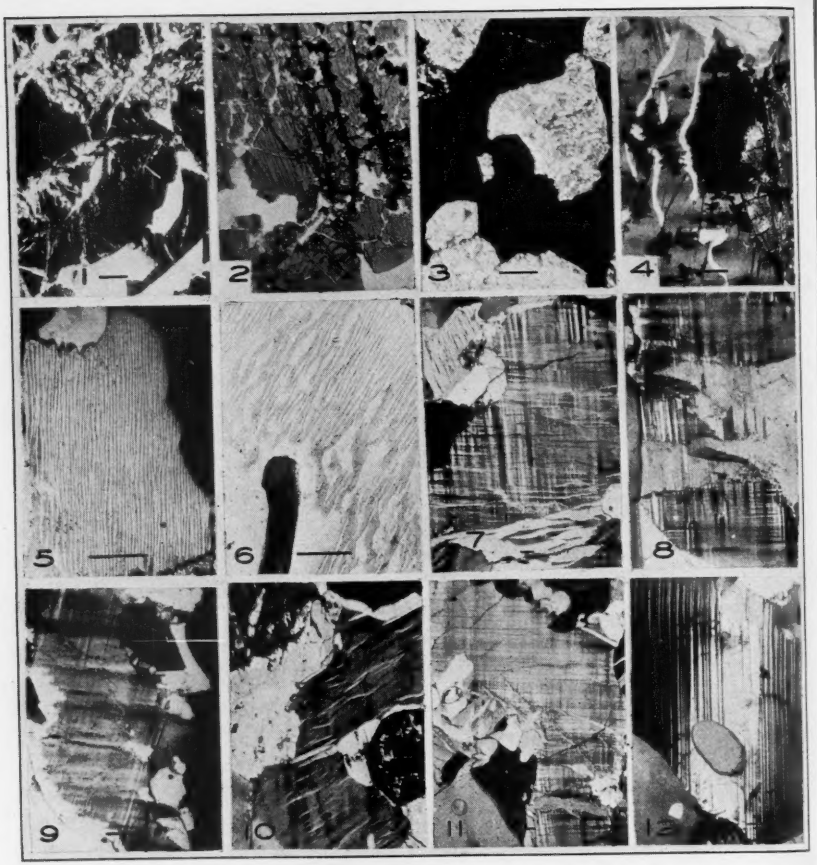
Gallagher is puzzled by the quartz-hastingsite relations. He says the mineral "may be interpreted either as early hastingsite cut apart by later quartz or late metasomatic hastingsite containing unreplaced quartz residuals. Most of the hastingsite . . . is late, possibly . . . the last mineral to form except for the calcite and chlorite."[21]

Probably both processes operated to produce the hastingsite. Gallagher and I may differ upon the degree of emphasis to be placed upon the two suggested methods.

[19] Kemp, J. F.: New York State Mus. Bull., 119: 68, 1908.

[20] This miners' term Gallagher has adopted in his discussion at Lyon Mountain. I may not be entirely justified in applying it to Mineville. However, it proves to be a very convenient term.

[21] Op. cit., p. 39.



FIGS. 1–12. Scale line represents 0.1 mm. Polarized light except for Fig. 11. Fig. 1. Pyroxene partially replaced by late quartz and vein calcite, Hammondville. Fig. 2. Metasomatic magnetite in altered pyroxene, Hammondville. Fig. 3. Brown hematite derived from altered pyroxene, Palmer Hill. Fig. 4. Brown hematite derived from corroded pyroxene enclosed in later myrmekite, Palmer Hill. Fig. 5. String perthite in wall rock, Cook Hill. Fig. 6. Albite replacing string perthite, Cook Hill. Fig. 7. Albite replacing microcline, wall rock,

Hypersthene.—An orthorhombic pyroxene, brown in color, occurs in the basic varieties of the wall rock. Like the diopside-acmite augite, it seems out of place in a rock with such a high quartz content. It would seem to be an inheritance of the magma from which the rock was derived by magmatic differentiation. Indices of refraction point to a composition[22] of about 72 per cent enstatite and 27 per cent ferrosilite. This is a hypersthene according to the nomenclature proposed in 1936.[23]

Olivine.—On the southern slopes of Palmer Hill green quartz-augite syenite contains an olivine. Its presence in a quartz-rich rock is most unusual.[24] Its composition is unknown. The mineral occurs in irregularly shaped grains exhibiting considerable corrosion. I have not observed it in wall rocks close to magnetite deposits; perhaps it has been destroyed by subsequent metasomatism. This mineral also seems to have been inherited.

The Feldspars.—The chief feldspar in metasomatically unaffected granite is the familiar microperthite, generally orthoclasic, in places microclinic, carrying blebs of albite-oligoclase. The latter are stringlets, strings, and rods of my nomenclature.[25] Elsewhere[26] I have given the evidence supporting the view that these bleb-shape sizes are due to exsolution and are not the result of replacement. The ore-forming metasomatic processes did, however, cause additional perthitic intergrowths by replacement in the form of plumes, or bands. Consequently, in metasomatically affected granite *both* exsolution and replacement perthites occur. A single theory is inadequate to explain the perthites in most of these rocks.

Jackson Hill. Fig. 8. Albite replacing microcline, Palmer Hill. Fig. 9. Albite rimming microcline, Winter Mine. Fig. 10. Albite rimming microcline string-rod perthite, Palmer Hill. Fig. 11. Late quartz replacing albite metasomatized microcline, wall rock, Jackson Hill. Fig. 12. Early quartz inclusion in magmatic oligoclase-andesine wall rock granite, Arnold Hill.

22 Bowen, N. L., and Schairer, J. F.: Am. Min., 20: 547, 1935.

23 Alling, Harold L.: The Interpretative Petrology of the Igneous Rocks, New York, 1936, p. 85.

24 Kemp, J. F., and Alling, H. L.: New York State Mus. Bull., 261: 48, 1925.

25 Alling, Harold L.: Plutonic perthites. Jour. Geol., XLVI: 143, 1938.

26 Op. cit., p. 154.

On the reasonable assumption that orthoclase is a high temperature modification of potash feldspar, its presence in these rocks points to the relatively hot conditions prevailing during its crystallization. Later albitic replacements seem to have caused (or permitted) some of the orthoclase to assume the form of microcline. A little oligoclase-andesine as a magmatic original is generally present and is distinguished from pegmatitic or metasomatic albite-oligoclase by textural relationships and by the presence of twinning.

Quartz.—There are clearly several generations of quartz. There is the usual late magmatic quartz of the granite, always anhedral and occupying spaces between the pyroxene and microperthite. It may or may not exhibit strain shadows under crossed-nicols.

Another type is generally optically strained and occurs cutting the other minerals. It invades the pyroxene, separating the latter into shredded fragments, it cuts, rims, and coats the feldspars including the magmatic albite-oligoclase. It is accompanied by metasomatic magnetite (the ore magnetite). In fact, this quartz is definitely later than all the other minerals above listed. To my mind it is the medium or vehicle by means of which the metasomatic magnetite was introduced. The quartz has the optical appearance of "vein" matter. It could be, as far as the microscope reveals, (*a*) deuteric, (*b*) pegmatitic, (*c*) pneumatolytic, or (*d*) hydrothermal in origin. Discussion of this is deferred to a later page.

The third type is the one about which much uncertainty prevails. It occurs as inclusions within the pyroxene, microperthite, and the magmatic plagioclase. It is not optically continuous with the adjacent quartz touching the host minerals. It may also differ from the outside grains in lacking strain shadows and in the percentage of gas bubbles. These two observations lead to the conclusion that it belongs to a still different generation.

Taking the fact that the third type occurs as inclusions at its face value (?), it should be older, that is, older than even the pyroxene. That means older than the magmatic differentiation

within the anorthosite-syenite-granite-gabbro magma. The only source for such quartz is the Grenville series of ancient sediments and the older Laurentian granite. The pre-(Algoman) granite metagabbros (ortho-amphibolites) lack sufficient quartz to be an important contributor. Therefore it may be either Grenville or Laurentian.

This theory is based upon two likely assumptions: the presence of such rocks invaded by the (Algoman) granite and effective assimilation. Both I believe occurred.

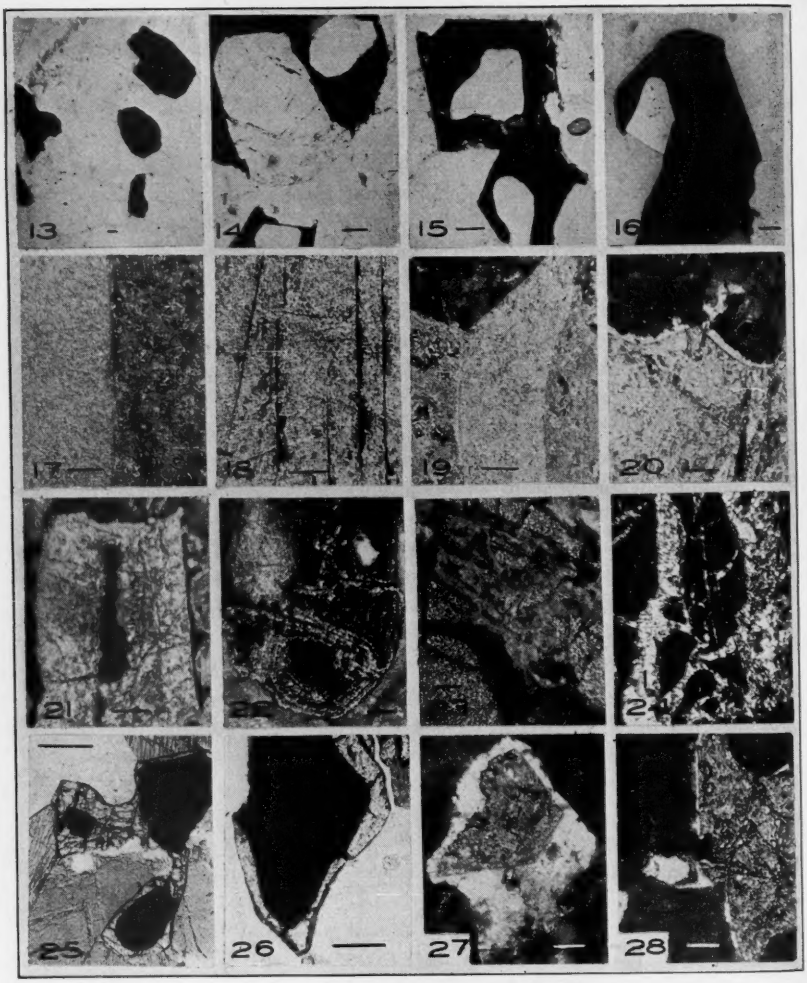
Colors of Opaque Minerals.—In addition to the usual vertical illuminator I have been using the Leitz Ultropak lamp-lens equipment to establish the identity of opaque minerals in thin sections. I have used about 11 volts in the bulb and the blue glass filter disc. This does not give perfect "daylight" rendering, nevertheless, the reader can reproduce these conditions. The following color determinations have greatly assisted me in establishing the sequence of events. This instrument has become a necessity rather than a mere accessory. The opaque minerals in the rocks and ores are not all of the same color.[27]

The accessory magnetite is steel black with just a touch of blue. The introduced metasomatic magnetite possesses a slight violet tint. If the grains are small, or if too low a magnification is employed, determination between the two types by color alone is not at all certain. But by reproducing the colors on cards with colored and metallic pencils and the use of a camera lucida, identification is facilitated and is more positive. This must mean a difference in composition.

Magnetite.—There are several ages of magnetite; some is early and some late. The first is accessory, the others were introduced. The euhedral, in places even ideomorphic, magnetite is minor in amount. It is the irregular shaped grains of the introduced and replacing magnetite that constitutes the ore. The accessory magnetite is associated texturally with zircon and accessory apatite, which are earlier than the magnetite.

The metasomatically introduced magnetite takes so many forms, replaces so many minerals in so many different ways that I cannot

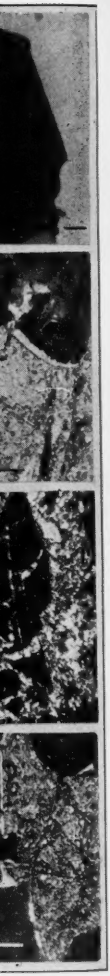
[27] Kodachrome photomicrograph transparencies very easily establish this.



FIGS. 13–28.

but believe that it was introduced over a relatively long period at various temperatures. In fact it can (and should) be dealt with not as the product of a single process, occurring during a single period, but rather that of a series of overlapping processes. At Palmer and Arnold Hills, these different processes can be separated somewhat, I believe, and can be recognized as periodic. Perhaps at Lyon Mountain the ore-forming processes were less extended, at least that is the impression I have obtained from reading Gallagher's bulletin. However, my studies of slides from there, even though I have had no experience on the ground, have suggested that after all Lyon Mountain may not be so different from other localities in this respect.

Martite.—Martite is an important constituent of many Adirondack deposits. It is not desired by the practical miner as its low magnetic characteristics cause it to land upon the tailing pile, causing loss of iron in the concentrates. Arnold Hill is especially noted for its presence. Martite, under the Ultropak lamp, is



FIGS. 13–28. Scale line represents 0.1 mm. Fig. 13. Accessory and metasomatic magnetite in late quartz, Mineville. Fig. 14. Metasomatic magnetite in late quartz, Arnold Hill. Fig. 15. Metasomatic magnetite in late quartz. Two grains of zircon in right center, Arnold Hill. Fig. 16. Metasomatic magnetite in late quartz, Mineville. Polarized light. Fig. 17. Metasomatic magnetite, right, and martite, left, ore from Palmer Hill. Ultropak reflected light. Fig. 18. Ilmenite rods in magnetite, Lake Sanford. Ultropak. Fig. 19. Martite replacing metasomatic magnetite in garnet contact rock, Palmer Hill. Ultropak and plain transmitted light. Fig. 20. Martite (crescent-shaped) rimming metasomatic magnetite, Mineville. Ultropak. Fig. 21. Mixed aggregate of martite replacing magnetite, Arnold Hill. Ultropak. Fig. 22. Zonal replacement of magnetite by martite, Paradox Lake Quad. Near Skiff [?] mine. Silverman illuminator and plain transmitted light. Fig. 23. Brecciated martite ore, veined by red jasper, Arnold Hill. Silverman illuminator. Fig. 24. Brecciated martite ore veined by red jasper, Arnold Hill. Polarized light. Fig. 25. Metasomatic magnetite rimmed by late sphene (titanite) in Grenville inclusion, Mineville. Fig. 26. Metasomatic magnetite rimmed by sphene, Mineville. Fig. 27. Late magnetite rimmed by leucoxenized sphene, Arnold Hill. Ultropak. Fig. 28. Pyrite, white grain, left center, margined by accessory magnetite. Right half is metasomatic magnetite rimmed on the left by leucoxenized sphene, Arnold Hill. Ultropak.

steel blue in color and has a smoother surface than magnetite. It is common in many ores from most localities. Palmer Hill, the Cheever Mine, Hammondville, and Mineville all contain some martite (Figs. 17, 19–21). The problem of its origin is an intriguing one. It commonly rims, penetrates the margins of the introduced magnetite, and follows fractures and replaces the magnetite. It is definitely later and the conditions bringing about its formation must have come after the introduction of the bulk of the metasomatic magnetite.

There are two natural viewpoints regarding its origin. First, that the martite is a mineral distinct from magnetite, but like the magnetite, it was introduced. The other view, which is in contrast, is that the magnetite was oxidized to martite, a case of "conversion."

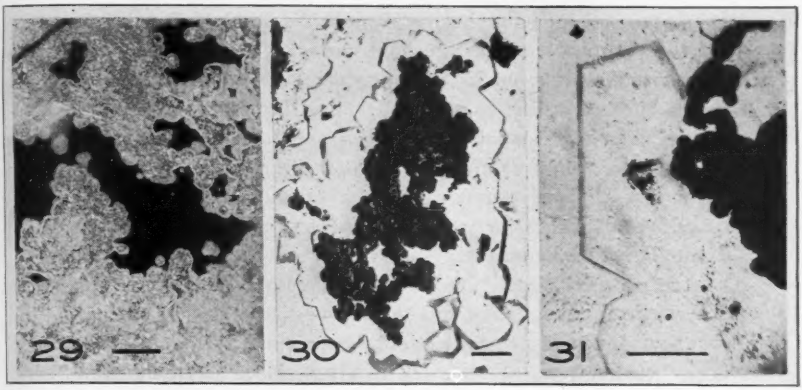
Newland [28] has suggested that the martite was derived from solutions accompanying the intrusion of the late Precambrian (Keewenawan) diabase dikes. I have elsewhere [29] expressed this doubt. There is no physical relation between the amount of martite in the ore and the presence, direction or width of the dikes on Palmer Hill. A dike 11 feet wide diagonally cuts the ore. Specimens from alongside the dike contain a variable amount of martite, from none to 54 per cent.

Another suggestion is that martite is due to weathering. The three ore bodies on Arnold Hill [30] were known as the "blue vein," with a high martite content, the "gray vein" with an intermediate amount, and the "black vein" consisting of magnetite. These characteristics continued to the bottom of the mine, probably 800 feet. But there is no indication of weathering. The feldspars are fresh. One would suppose that weathering would produce limonite from magnetite, not martite. I agree with Newland that "the martite is not a superficial development." [31] A hypogene origin is clearly indicated.

The present conception seems to be that martite is isometric

[28] Newland, D. H.: Econ. Geol., XVII: 301, 1922.
[29] Alling, H. L.: Econ. Geol., XX: 353–354, 1925.
[30] Newland, D. H.: New York State Mus. Bull., 119: 98, 1908.
[31] Newland, D. H.: Econ. Geol., XVII: 301, 1922.

and at least partially isomorphous with magnetite and, consequently, forms with magnetite a more or less continuous series of solid solutions from magnetite to oxidized magnetite[32] (or oxymagnetite[33]). It is known that "hematite shows a sharp



FIGS. 29–31. Hematite. Scale line represents 0.1 mm. Fig. 29. Late hematite and vein quartz cutting ore, Mineville. Ultropak. Fig. 30. Late hematite in vug quartz, Mineville. Negative print. Reflected and plain transmitted light. Fig. 31. Late hematite in vug quartz, Mineville.

inversion point at 678° C, but the characteristics of the high temperature form are unknown."[34] It would simplify the problem if martite should be assumed to be this high temperature modification of hematite.

Hematite.—Hematite is not an important constituent of the commercial ores. There are several distinct forms. It occurs mixed with martite in fine grained aggregates giving a general purplish color caused by the blue of the martite and the red of the hematite. If martite is a high temperature form of hematite this purple aggregate could be explained by its inversion to hematite. It is possible that the solubility of hematite in magnetite is less

[32] Winchell, A. N.: Elements of Optical Mineralogy, New York, 1933, p. 63.
[33] Winchell, A. N.: Am. Min., XVI: 270, 1931.
[34] Winchell, A. N.: Elements of Optical Mineralogy, New York, 1933, p. 45.

than martite in magnetite. If so, exsolution could explain these aggregates.

Also hematite, fairly free of martite, coats, rims, and veins the magnetite, martite, and the hematite-martite aggregate. Microscopic examination certainly gives the impression that this hematite is an introduced mineral probably closely following the martite. Probably it was a colloid, now it is crystallized.

As a still later event is the introduction of hematitic stained quartz and red jasper.

The theory of partial isomorphism and inversion of martite would be consistent with the microscopic observations.

Sphene.—Sphene (titanite) is an interesting mineral in these rocks. It also occurs in two distinct ways, of two contrasted ages.

Similarly one is accessory and early and the other late and introduced. Gallagher [35] reports that accessory sphene is absent at Lyon Mountain. The late sphene occurs as large anhedral grains, adjacent to magnetite, and also as rims around it. This is particularly true of metasomatically replaced Grenville sediments (Figs. 25–28). In the "grayband" at Mineville these rims are common and very striking. The rims have the appearance of "reaction rims" or coronas. Gallagher [36] holds that they "are not reaction rims in the ordinary sense," because (1) they vary too much in thickness, (2) rims usually surround several grains, (3) they coat other minerals than magnetite, especially apatite, and (4) are independent of adjoining minerals. They do, however, seem to avoid quartz, but in such case the sphene may have been destroyed by the introduced quartz. (5) The titanium content does not commensurably increase with the amount of magnetite. Gallagher believes that the sphene was introduced "probably with the magnetite." He makes no further attempt to account for the rims.

The sphene is obviously later than some of the metasomatic magnetite. It likewise replaces the other minerals but has an affinity for the introduced magnetite and seems almost entirely to avoid the early accessory magnetite grains.

[35] Op. cit., pp. 36, 39.
[36] Op. cit., p. 41.

In the Lake Sanford ores the titanium is largely in the form of ilmenite (chiefly $FeTiO_3$) intergrown with magnetite, which produces a high titanium concentrate.

The relatively low silica content of the anorthosite wall rock seems to have prevented the formation of sphene (chiefly $CaTiSiO_5$). Ilmenite at high temperatures is soluble in magnetite. Sphene apparently is not. This is indeed fortunate for the miner; the brittle sphene is milled off the grains of magnetite. There seems to be good reason to believe that there is some relation between sphene and magnetite to account for the rims.

The ilmenite-rich magnetite of the Lake Sanford ores constitutes an intergrowth due in all probability to exsolution. Can it be possible that the sphene, or some of the chemical elements of that mineral, have been forced out of the magnetite by a process like exsolution? If so, this would help explain the close association of two minerals. Rims of sphene around accessory magnetite are exceedingly rare and when they occur are extremely narrow.

Sphene is particularly common in metasomatically affected Grenville sediments, such as the "grayband." Generally the sphene is fresh and unaltered to leucoxene. In metasomatically replaced granite, the sphene rims are narrower and almost always leucoxenized.

Pyrite.—The Adirondack magnetites are noted for their low sulphur content, yet pyrite can be found as small euhedral grains in the ores and the magnetite-rich granitic wall rocks. By its detached position and ideomorphic habit much of it is regarded as a normal accessory mineral. It appears to be very early in the order of crystallization. In one case (Fig. 28) the Ultropak lamp reveals that an euhedral grain is surrounded by bluish magnetite with no leucoxene coating. The blue color and absence of sphene or leucoxene strongly support the view that it is accessory magnetite and is later than the pyrite. This seems to establish the order of crystallization.

In the Lake Sanford ores, pyrite, chalcopyrite and bornite occur more closely associated with silicates. In these ores a later dating of the pyrite seems likely.

In wall rocks that have assimilated considerable Grenville sediments, pyrite commonly occurs associated with biotite and graphite in exactly the manner as it is found in the graphite schists.[37] This pyrite is, in all probability, organic in origin.

Biotite.—The ore-formation granite is generally free from micaceous minerals. The common ferromagnesian mineral is diopside-acmite augite. In those localities where the presence of Grenville sediments can be substantiated, the wall rock as well as the ore contains biotite. In the Cook, Winter, and Jackson Hill localities in the Ausable quadrangle, this is particularly so. I think it is safe to assume that, as a general rule, biotite is indicative of assimilation of Grenville sediments.

An interesting occurrence of biotite in hastingsite in a Grenville inclusion from Arnold Hill is shown in Fig. 36. A narrow flake of biotite lies embedded in hastingsite giving the impression that the amphibole has recrystallized around it. This suggests that there must have been a history back of the hastingsite, going back to the deposition of the Grenville sediments, the formation of amphibole or pyroxene by induration and its metamorphism, and its recrystallization into the present hastingsite.

In a few instances small flakes of biotite occur at the margins of magnetite. Gallagher suggests a reaction origin for it. He does not enlarge upon this interpretation.

Garnet.—On Palmer Hill garnet skarn rocks occur physically associated with Grenville sediments. Many specimens have been collected that consist solely of yellow brown garnet and magnetite (or martite). These give every appearance of being the usual type of contact rocks. I have no doubt that that is just what they are: Granite-Grenville contact zone products; the magnetite would not be the introduced metasomatic form but a higher temperature type. It, however, has been replaced in part by martite, thus furnishing another line of evidence for the importance of the associated Grenville in the mechanics of the formation of the ore. In the commercially important deposits I doubt very much that such action materially contributed to the bulk of the ore.

[37] Alling, Harold L.: New York State Mus. Bull., 199: 65, 1917.

Graphite.—The use of the Ultropak lamp reveals the presence of a few flakes of graphite generally associated with biotite or with pyrite. The graphite is dull steel black, readily distinguished from the other opaque minerals with this useful equipment. It is believed to be organic and derived from the Grenville. Pyrite is rare with the graphite, as it is in many of the graphite schists.

Chlorite.—The pyroxene in the basic pegmatites has been altered to chlorite. It appears to have been produced by the hydrothermal agents that introduced the jasper and calcite. Magmatic attack did not, apparently, form chlorite. This gives a suggestion regarding the temperature differences.

Allanite.—In some of the acidic pegmatites on Palmer Hill and at Mineville, brown allanite occurs in poorly crystallized masses. This is one of the few truly pegmatitic minerals recognized.

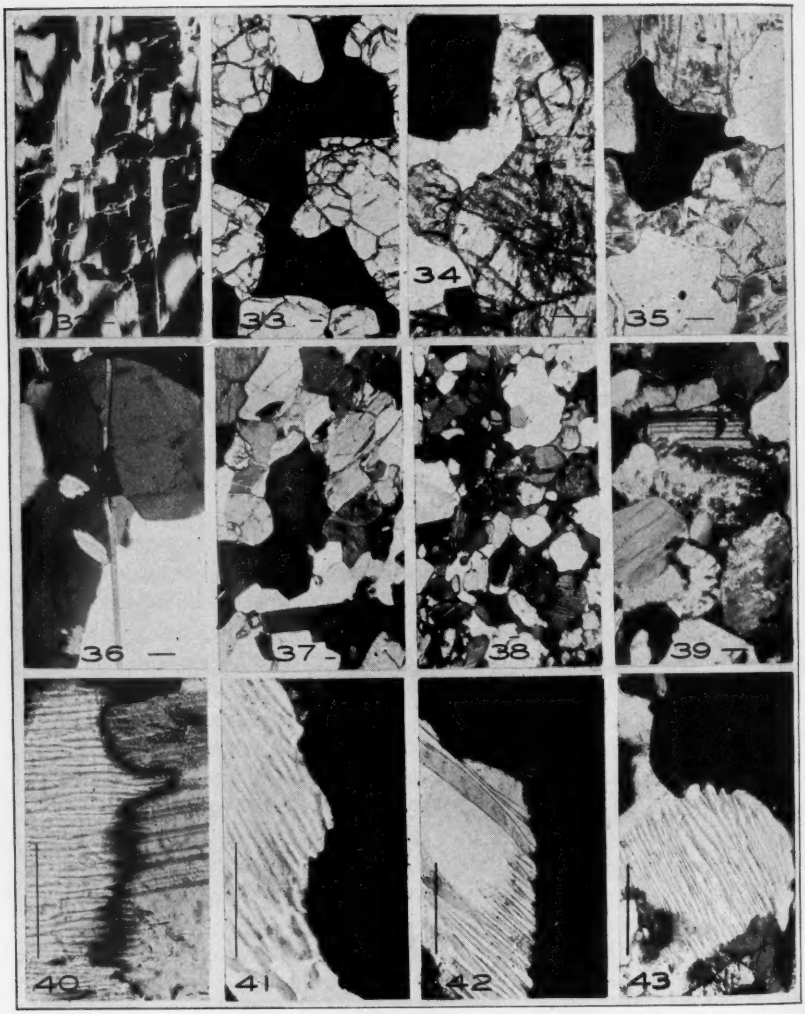
Tourmaline.—Both black and brown tourmaline occur in pegmatites and in pegmatized wall rocks. Some are relatively well crystallized.

Calcite.—Vein calcite occurs in some localities, especially Palmer Hill. Calcite is associated with the red jasper cutting brecciated martite ore. It is obviously a hydrothermal introduction.

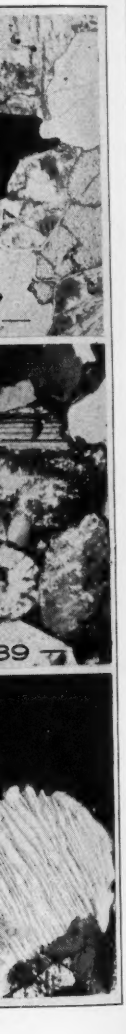
Molybdenite.—In some of the garnet rich rocks, evidently the result of contact action, small flakes of molybdenite have been identified by the Ultropak lamp. The amount is very small.

Fluorite.—An interesting rock occurs on Palmer Hill;[38] a fluorite-bearing granite. Fluorite constitutes 25 to 30 per cent of the rock. On fresh exposures it is violet to purple in color which fades in the course of a week to a pale greenish yellow and eventually becomes colorless. It occupies a normal position in the rock. From textural relations it appears to have crystallized about the same time as the microcline-microperthite. The introduced magnetite, now completely changed to (replaced by) martite, replaces the feldspar and the fluorite to the same degree.

[38] Newland, D. H.: New York State Mus. Bull., 119: 100, 1908.



FIGS. 32–43.



PEGMATITES.

Most mines are seamed by pegmatites of various kinds that have many curious and perplexing relations to themselves and to the wall rock. Gallagher recognizes[39] three types: (*a*) "orange," (*b*) "augen," and (*c*) "white" pegmatites. On the other hand I have classified them as the acid and basic types. It is not possible to completely reconcile these two nomenclatures. Of course those at Lyon Mountain may justify a special scheme. The acid and the "orange" pegmatites are chiefly composed of perthite. This is distinctly different from the granitic perthite. The pegmatitic forms are microclinic with only a few exsolution strings and rods, but with abundant replacement plumes, or bands. It commonly carries regularly shaped flakes of hematite that give the rock the reddish or "orange" color. Quartz is mostly a minor constituent. A few small grains of zircon, apatite, sphene, tourmaline, fluorite, spinel, and allanite occur. The grains of magnetite that occur in these pegmatites give every appearance of being introduced, although it is not possible to be sure in every case. Martite is comparatively rare.

The basic pegmatites vary more in grain size and in mineralogy. The chief mineral is an albite-oligoclase ($Or_2Ab_{87}An_{11}$), sometimes untwinned. It lacks the hematite of the more acid types

FIGS. 32–43. Scale line represents 0.1 mm. Polarized light except for 33–36. Fig. 32. Pegmatitic perthite. Acid pegmatite, Palmer Hill. Fig. 33. Contact magnetite in yellow garnet rock, Palmer Hill. Fig. 34. Accessory and metasomatic magnetite in pyroxene, Cook Hill. Fig. 35. Metasomatic magnetite in fluorite (rough grains) granite, Palmer Hill. Fig. 36. Flake of biotite embedded in hastingsite amphibole, Arnold Hill. Fig. 37. Grenville paramphibolite, Dresden formation near Cheever Mine. Fig. 38. Grenville arkosite inclusion in wall rock, Arnold Hill. Fig. 39. Grenville arkosite inclusion, Arnold Hill. Fig. 40. Comb texture between magmatic perthite, left side, and deuteric albite-oligoclase, right side, wall rock, Cook Hill. Fig. 41. Comb texture between magmatic perthite and metasomatic magnetite, Cook Hill. Fig. 42. Comb texture between deuteric replaced magmatic perthite and metasomatic magnetite, Cook Hill. Fig. 43. Comb texture between magmatic perthite partially replaced by deuteric perthite and corroded pyroxene, Cook Hill.

[39] Op. cit., pp. 26–28.

and, therefore, they are light colored. It has commonly been scapolitized. Quartz is generally abundant. However, not all of it is primary in the pegmatites. The introduced quartz possesses strain shadows. The chief ferromagnesian mineral is the familiar diopside-acmite augite, emerald green in color. It varies greatly in amount. In rich phases it probably comes under Gallagher's classification of "augen" pegmatite. Like the pyroxene in the granite, it is commonly corroded and shattered, but in the pegmatites it may be altered to chlorite. Magnetite occurs in many forms. Some is probably primary but the bulk is introduced. Martitic rims and replacements are much more common in these basic pegmatites than in the acid ones. Accessory minerals include brown hornblende, rarely muscovite, apatite, black tourmaline, molybdenite, and sphene. Alteration minerals include scapolite, and epidote, as well as the chlorite.

The pegmatites form confused criss-cross patterns. They cut each other and also the ore. They follow the banding of the wall rock and the ore for some distance only to bend sharply and fan out producing pegmatitized granites. Repeated examinations of Palmer Hill have given me the impression that these acid and basic pegmatites alternated, were repeated, and consequently were periodic. They performed an important function, in some instances, in the introduction and distribution of the ore.

In addition to the rôle they played in the origin of Adirondack magnetites, these pegmatites emphasize that they are high temperature phenomena directly connected and part of the magmatic stage. They are the kind regarded by Landes[40] as intermediate and of the syenite type. Hydrothermal activity was not the dominant process. It was not, however, entirely lacking as is shown by the sericitization, the scapolitization, and the introduction of sulphides.

QUARTZ VEINS.

Associated with the pegmatites are veins, which perhaps should be regarded as only a quartzose phase of the pegmatites. They

[40] Landes, K. K.: Origin and classification of pegmatites. Am. Min., 18: 33–56, 95–103, 1933.

carry magnetite, a little pyrite, chalcopyrite, and martite. Other phases contain a carbonate, probably calcite. These are abundant on Arnold Hill, cementing brecciated martitic ore (Figs. 23–24). Still other veins carry chalcedonic quartz and opal. If these are true veins it implies that hydrothermal solutions were active during the late history of ore deposition.

At Mineville specimens from a mine dump reveal hydrothermal deposition of bright red hematite and vug quartz (Figs. 29–31).

SEQUENCE OF EVENTS.

Granite Wall Rock.—It is obvious that both the diopside-acmite-augite and the hypersthene are the earliest minerals. They appear to have been inherited from the basic magma from which the syenite series was derived. The augite exhibits all degrees of corrosion and alternations. They were not stable in the granitic environment.

The first orthodox accessory mineral is pyrite. It was followed by apatite and zircon. Accessory magnetite is believed to have crystallized later as it rims the pyrite in a number of cases and shows xenomorphic relations towards the apatite and zircon. Accessory sphene occurs as little cubes, surrounded in places by the later introduced replacing sphene, sometimes making identification of the accessory type difficult. This completes the list of the common accessories.

The first of the essential minerals is plagioclase. It is not abundant as a rule. Care must be taken to distinguish it from the introduced plagioclase. The primary mineral is mainly oligoclase ($Or_3Ab_{70}An_{27}$), less commonly it is an andesine (Or_2Ab_{60}-An_{38}); mostly it is twinned, in contrast to the replacing albite-oligoclase, which may be untwinned.

The dominant mineral in the rock is perthite. Without much question it was originally a soda orthoclase, which through the processes of inversion and exsolution became a microcline-microperthite of the type I have recently called stringlet-string-rod perthite.[41] It would appear that the change from orthoclasic to

[41] Alling, Harold L.: Jour. Geol., XLVI: 143, 1938.

microclinic types did not necessarily occur at any one stage in the history of the rock, but was dependent upon local stress conditions. Some specimens are entirely orthoclasic and others consist wholly of microcline. Intermediate rock types are found, containing both forms.

Quartz grains complete the orthomagmatic history of the granite. The crystallization sequence is shown in Table 1.

Grenville-Granite Migmatites.—The great variety of types in this catagory make a simple statement difficult. It is believed that the amphibole and the biotite are assimilated material. The amphibole is not invariably the grass-green hastingsite, but may

TABLE 1.

I. UNAFFECTED GRANITE. MINERALOGICAL SEQUENCE.

Mineral.	Inherited.	Magmatic.	Deuteric.	Pneumatolytic Metasomatic.	Hydrothermal.
Pyroxene	—				
Pyrite		–			
Apatite		–			
Zircon		–			
Magnetite		–			
Sphene		–			
Olig. And.		—			
Or → Perth		——			
Quartz		——	——		

II. PARTIALLY METASOMATIC AFFECTED GRANITE.

Mineral.	Inherited.	Magmatic.	Deuteric.	Pneumatolytic Metasomatic.	Hydrothermal.
Pyroxene	——				
Pyrite		–			
Apatite		—			
Zircon		—			
Magnetite		—			
Sphene		—			
Olig. And.		——			
Or → Perth		——			
Quartz		–	—		
Ab — Olig.			——		
Myrmekite			—		
Magnetite				——	
Sphene				—	
Quartz				——	

TABLE 1 (*Continued*).

III. ORE.

Mineral.	Inherited.	Magmatic.	Deuteric.	Pneumatolytic Metasomatic.	Hydrothermal.
Pyroxene	——				
Or → Mic.-Perth.		——			
Quartz		-	——		
Ab — Olig.			——		
Magnetite				——	
Quartz					
Martite				——	
Hematite					——
Jasper					—
Calcite					—

be a reddish brown hornblende. The biotite is clustered about cores of hornblende suggesting, none too positively perhaps, that the biotite came after the hornblende and recrystallized after it.

The plagioclase is commonly andesine and is regarded to be, in large measure, a Grenville contribution. Clear grains of oligoclase show allotrimorphic relations towards the andesine. Consequently, this feldspar is believed to be a granite contribution. It becomes a question of unnecessary detail whether the oligoclase should be regarded as an introduced mineral or not.

The picture I have in mind, guided by microscopic observations, is that the formation of this migmatite was more of a lit-par-lit injection and reactive incorporation rather than an actual melting in of Grenville material. Perhaps magmatic soaking conveys the intended thought. Orthoclase and quartz from the granite complete the list. The orthoclase became perthite by exsolution.

METASOMATISM.

We come now to the interesting problem of the origin of the magnetite. It is recognized this was brought about by a complicated series of interlocking, overlapping, in some mines continuous processes, whereas in other cases they may have been alternating, perhaps even periodic.

The earliest form of metasomatism was the introduction of the albite-oligoclase ($Or_3Ab_{87}An_{10}$) and its replacement of the "ex-

solutionized" perthite. This plagioclase rims and penetrates the perthite, framing the grains and producing plume and band perthites. (Figs. 5–10.) The two sets of plagioclase blebs, the stringlet and string types, on the one hand, have a slightly different composition from the plume-band forms, on the other. Many grains of albite-oligoclase give the impression that they represent completely replaced potash feldspar and give the rock a quartz monzonitic composition. The albite-oligoclase apparently chiefly confined its metasomatism to the potash feldspar and sparingly attacked the primary oligoclase-andesine. The diopside-acmite-augite was little affected by it. This replacement by sodic plagioclase can readily be assigned to late magmatic or deuteric action.

Following the albite-oligoclase is quartz and magnetite. I linked the two together because there is no microscopic evidence to separate them. Besides, there seems a need for an additional mineral to act as a "flux" to lower the melting point of magnetite to temperatures commensurate with the conditions probably prevailing during this stage.

Both the quartz and the magnetite replace pyroxene, albitized perthite and granitic quartz. Selective replacement seems to have occurred. This can only be recognized in the wall rock not too close to ore bodies; the ore itself is a complete replacement phenomenon. The introduced quartz actively attacked the albitized perthite, in some instances produced myrmekite, which in some cases encloses brown hematite derived from magmatic attack upon pyroxene (Fig 4). The magnetite seems to have favored the primary granitic quartz. It did not, however, ignore the perthite and the pyroxene. Some thin sections show that it was the pyroxene that was the first replaced, producing granitic rocks with no ferromagnesian silicate minerals. Others, however, indicate a different selection. Was this controlled by differences in temperature or a variable composition of the replacing material? Relative selectivity of the metasomatic minerals is shown by the comb textural relations between magnetite and the exsolutionized perthite. The magnetite has penetrated deeper into the potash

feldspar in the microcline, consequently the albitic string-blebs penetrate into the magnetite; they mutually interpenetrate (Figs. 41–42). Similar relations exist between perthite and the introduced albite-oligoclase (Fig. 40).

Another example of selective replacement is the case of comb texture between string perthite partially replaced by introduced oligoclase and diopsidic-acmitic augite. The pyroxene sends prongs into the plagioclase but not into the potash feldspar. I believe the albite-oligoclase partially replaced the pyroxene where the feldspar was thickest (Fig. 43).

In a few instances a little biotite margins metasomatic magnetite. Gallagher has noted this and suggests a reaction origin for it,[42] although he offers no details.

AGENT OF METASOMATISM.

Although there is no question that metasomatism is largely responsible for the magnetite deposits of the Adirondacks, the agency by means of which it was accomplished now needs to be discussed.

It is obvious that it began as part of the magmatic process and other processes continued closely associated with it. The term that best fits the early stages is deuteric. But it can not be used for the pegmatitic and quartz veins. For them then the name hydrothermal is only partially applicable, because division between the two is really a matter of geologic classification. I would stress the gradation rather than the separation.

Now as to the agent. The magnetite probably was not introduced as a liquid melt because of the high melting point (about 1538–1550° C), which is about the same as that of anorthite. The same objection to a melted magnetite has been raised in the case of plagioclase in the problem of the origin of the anorthosites.

If the ore was not introduced as an ore-magma then a fluxing agent or vehicle is necessary. Either a liquid or a gas would do. In the deposition of the late quartz, jasper and vein calcite hydrothermal solutions are clearly indicated. It would be a simple

[42] Op. cit., p. 45.

matter to infer that these were the chief agents in the introduction of the magnetite as well. Perhaps this would be justified. But the fashion today is to call upon gaseous transfer. This would justify the use of the term pneumatolytic. The criteria for the recognition of gaseous transfer and especially its separation from hydrothermal activity are really nonexistent. Consequently, the answer to this question must rest at this time upon theoretical considerations.

Some have suggested that the temperature of pneumatolytic action takes place above the temperature of the formation of chlorite. If this is a safe division marker, then the answer is that gas was the agent for the bulk of the introduced magnetite. This would leave the late stages to hydrothermal processes.

The miarolic cavities at Lyon Mountain certainly point to gas transfer. Hyperfusibles are usually considered to be rich in boron, chlorine, and fluorine. Possibly some of the large irregular grains of apatite, and certainly the fluorite of the fluorite granite of Palmer Hill, can be attributed to such gases. Scapolite can well be added to the list.

The conclusion reached is that pneumatolytic metasomatism was, in all probability, the *chief* process in the deposition of the magnetite ore bodies. But hydrothermal solutions unquestionably were responsible for the late stages.

SOURCE OF IRON RICH LIQUID

Every bit of evidence indicates that the iron came from the crystallizing granitic magma. But the usual theory of such phenomenon calls for a siliceous rather than an iron-rich liquid as the end phase result. Fenner's [43] studies of the crystallization of basalts led him to suggest that the final liquid was rich in iron. On the other hand, Bowen [44] has advocated a siliceous end product. The study of the Adirondack magnetite deposits leaves no doubt about the nature of this liquid in *this* case; it was iron-rich.

It is well to inquire into the physical chemistry controlling final

[43] Fenner, C. N.: Amer. Jour. Sci. (4), 29: 217, 1910.
[44] Bowen, N. L.: Amer. Jour. Sci. (4), 40: 161–185, 1915.

melts. Full information is not as yet at hand but in the system Na_2SiO_3–Fe_2O_3–SiO_2 [45] some definite suggestions are available. The formation of acmite can be expressed by the equation: $Na_2SiO_3 + SiO_2 + F_2O_3 \rightleftarrows 2NaFe(SiO_3)_2$ acmite. This is a reversible reaction. On heating acmite, hematite separates at 990° C. The hematite does not melt nor dissolve until a temperature of 1287° C is reached.[46] Between these two temperature limits solid hematite exists. Bowen traces the details of the crystallization of a melt composed of 2 per cent of Fe_2O_3, 92 per cent of acmite, and 6 per cent of $Na_5Fe(SiO_3)_4$. The latter is a compound not as yet identified in rocks. With different degrees of fractionation, the relative amounts of hematite, acmite, quartz, and the compound $Na_5Fe(SiO_3)_4$ are the products. In this manner Bowen, Schairer, and Willems show how iron-rich minerals may be the last to crystallize, and under other conditions quartz is late. It is significant that the pyroxene in the wall rocks of the Adirondack magnetite deposits contains acmite. The above may not be a satisfactory explanation.

CONCLUSIONS.

In attempting to summarize my conception of the processes and their products responsible for these ore deposits, I face a real psychological problem. To state that one of the chief processes was one of high temperature replacement, which I believe it was, may, I fear, give the impression that the magnetite was due to metasomatism alone. But without magmatic differentiation there would be no deposit. Likewise reactions resulting in iron-rich solutions or gases took place in crystallization of a granitic magma, otherwise no magnetite. It will defeat the purpose of this paper and be unfair to its readers to stress one process alone.

The main processes can be simply stated, but there were many others that played important functions whose significance at this time can not adequately be judged. The impressions I have ac-

[45] Bowen, N. L., Schairer, J. F., and Willems, H. W. V.: Amer. Jour. Sci. (5), 20: 405–455, 1930.

[46] Idem., p. 431.

quired through petrographic studies, which have extended over twenty years, are that of a series of overlapping, interfingering processes, beginning at high temperatures and ending with hydrothermal activity and calcite veining formed these ore bodies. Each mine and prospect pit has made its own contribution to the general picture. At the same time they have shown that one locality exhibits conditions that necessitate emphasizing certain factors, and in others slightly different processes were dominant. A study of one mine alone cannot result in a general group-theory applicable to all. This paper presents the general group-theory with occasional references to individual localities.

It is necessary to go back to the country rock into which the ore formation granite was intruded. The Grenville sediments, thousands of feet in thickness, themselves probably injected by the metagabbro and Laurentian granite, folded and faulted and metamorphosed, controlled the flowage phenomena of the Algoman series of igneous rocks. From a dioritic to gabbroic magma the anorthosite, syenite, granite and gabbro differentiated. The commercially called "non-titaniferous" magnetite is directly associated with the granitic phases whereas the "titaniferous" magnetites lie in anorthosite. The Grenville sediments not only governed the foliation but in many instances determined the shape and place of the ore bodies. Magmatic replacement of the Grenville took place on a large scale. Granitization through syntexis, not necessarily melting, produced migmatites.

These migmatitic rocks range in composition from nearly unaffected, and hence readily recognized, Grenville to granites with slight Grenville taint. It can be debated pro and con whether the wall rock of the "non-titaniferous" magnetites is one hundred per cent pure granite. I would vote no. At Lyon Mountain it may be nearly all granite, at Hammondville a large amount of Grenville is present, some as such and some incorporated in the granite. In other words magmatic assimilation was one of the important processes.

The granite, derived by differentiation from a more basic rock, contains some inherited minerals. The augite, hypersthene and

olivine (the latter is lacking close to the ore bodies) are not in equilibrium with the granitic substances. This suggests that erosion has brought the surface down, or nearly down to the place of differentiation.

The first granitic orthomagmatic essential minerals are the feldspars—originally a soda-rich orthoclase and an oligoclase-andesine. The orthoclase on cooling became supersaturated with albite and by exsolution became stringlet-string-rod-perthite. On further cooling the orthoclase became microcline.

Still at relatively high temperatures deuteric albite-oligoclase came in and continued to replace the perthite and the magmatic plagioclase. Quartz, overlapping, followed the replacing albite and in some instances produced myrmekite. Hence deuteric replacement took place.

Following and partially overlapping the deuteric quartz, came metasomatic quartz, magnetite, and, especially in Grenville-granite migmatites, sphene (titanite) attacked and replaced first the pyroxenes, then the feldspars, and then the magmatic quartz, but not magmatic accessory magnetite. Hence high temperature replacement occurred. Perhaps it was all by gaseous transfer. If so it was pneumatolytic metasomatism. I think it was in part, at least, by hot solutions, certainly not as a magmatic melt.

The metasomatic quartz and magnetite were evidently directly connected with the pegmatitic phases of the differentional products of the magma. There are pegmatites of various kinds, compositions and activities. They brought in more magnetite, did more replacing and brought about additional concentrations of magnetite. Kemp [47] says "We may think of the ore as being more or less akin to pegmatites in its formation." Surely these are late or end phase phenomena. Hence there was pegmatitic replacement.

Quartz, jasper and calcite veins complete the list of events. Consequently there was hydrothermal introduction and replacement.

[47] Kemp, J. F., and Ruedemann, R.: Geology of the Elizabethtown and Port Henry Quadrangles. New York State Mus. Bull., 138: 132, 1910.

No one process was wholly responsible. Many processes, including that of high temperature metasomatism, formed the ore.

For a summary I offer Table 1. The mineralogical sequences shown there naturally are generalizations and at the best are approximations. The length of each individual line indicates not the amount of the mineral but rather the time involved.

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ORE GEOLOGY OF THE DAY DAWN MINE, NEW GUINEA.

N. H. FISHER.

ABSTRACT.

The Day Dawn Mine is representative of late Tertiary mineralization, the alluvials derived from which have yielded 900,000 ozs. of gold since their discovery in 1926. The ore body is contained mainly within phyllite but is intimately connected with a quartz-biotite porphyry intrusion that has been subjected to intense hydrothermal alteration. In its inner portion the lode follows the porphyry-phyllite contact, but the richest ore occupies a fissure that cuts obliquely across the phyllite and then turns to conform to the strike and dip of the host rock, where the mineralization begins to die out. The average fineness of the gold is about 520 parts per thousand, and decreases with depth from the surface. The gold is contained in a series of small quartz stringers that traverse the payable mineralized zone, which averages three feet in thickness and ranges from 200 to 600 feet in length. Principal associated minerals are pyrite, and manganiferous oxidation products in the upper levels, although rhodocrosite, chalcopyrite, calcite, pyrargyrite, proustite and stephanite have also been recognised locally in small quantities. Silver values are high, the silver-gold ratio being 30:1, but silver is probably mostly contained in an insoluble manganite. Secondary enrichment has had some influence on the distribution of the gold, and even more upon that of the silver. Gold values, phenomenally rich in places near the surface, decrease with depth, very rapidly just near No. 2 level, and no exploration has been carried out below this level.

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INTRODUCTION.

THE Day Dawn Mine is situated on the left bank of the Merri Creek, a few hundred yards above its junction with Edie Creek, and at an elevation above sea-level of 6,500 to 7,000 feet. The mining center of Edie Creek is connected by 9 miles of motor road with Wau, the main center of the Morobe Goldfield, which is served, by aeroplane transport only, from the ports of Salamaua, 35 miles distant, and Lae, on the coast of Huon Gulf. Total cost of transport from the beach is 2d. to 3d. per pound, although at the time the Day Dawn Mine commenced operations, this cost was about 8d. The climate at Edie Creek shows little seasonal change; it is warm by day and cold at night, a result of the combined effects of its geographical position, only 8° 20′ south of the equator, and its elevation above sea-level. Annual rainfall averages about 105 inches; December, in which falls up to 25 inches have been recorded, is usually the wettest month, although high rainfall may occur in any month from October to April. The period from May to August is generally appreciably drier.

HISTORICAL NOTE.

The rich alluvials at Upper Edie Creek were discovered in February, 1926, but a few months elapsed before the existence of high values in Merri Creek was also realised. The Day Dawn lode, which owed its discovery to the presence of gold-bearing stone in the roots of a fallen tree, was located about the middle of 1927. A company was subsequently formed to work it and an Empire mill, driven by an engine supplied with steam by a wood-fired boiler, was installed. Production commenced in May 1931 at the rate of 400 to 800 tons per month, and in November 1932 another similar mill was added and production doubled. In June 1935 exhaustion of developed ore and decreasing values caused the company to close down. The Mine and plant were sold towards the end of 1936, and have since that time been worked in a small way by local syndicates.

The ore has been developel by four adits driven from the hill-

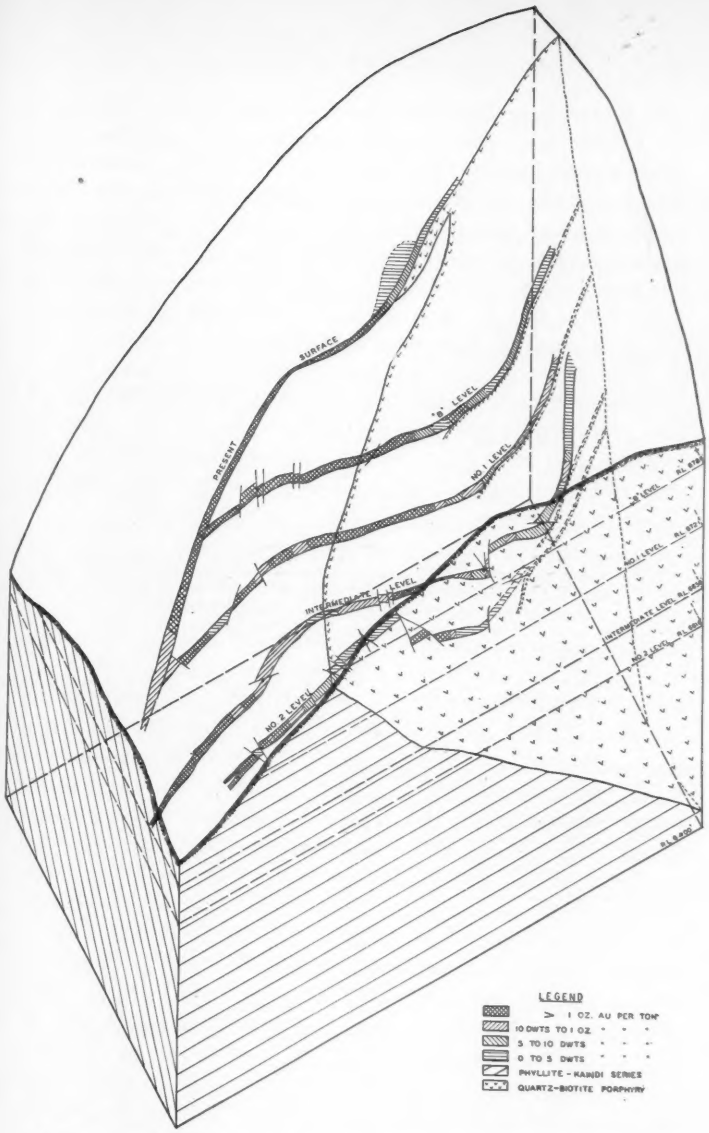

FIG. 1. Block diagram of the Day Dawn Lode, looking east. Sides of the block are respectively 57 and 147 degrees east of north. Workings on the various levels have, for clarity, been omitted. The parallel lines of the phyllite show approximately the direction of dip of the beds.

side, the two upper ones, the " B " (140 foot) level and the No. 1 (205 foot) level both entirely along the lode, and the Intermediate (270 foot) and the No. 2 (310 foot) levels, consisting of crosscuts to the lode with drives along it in either direction. Ore has been stoped by cut and fill methods and by open cut at the surface, the open cut also providing filling for the stopes. Mining has been carried out by European miners in charge of gangs of native laborers. No work has been done on the lode below No. 2 level, which is on the level of the mill floor.

Total production of the mine has been about 21,000 ozs. of fine gold from 41,500 ozs. of bullion. Recoveries, being by amalgamation only, have averaged approximately 68 per cent gold and 12 per cent silver. The decrease in head values is shown in Table I.

TABLE I.

TABLE SHOWING THE AVERAGE ASSAY VALUE OF THE ORE MILLED AND THE APPROXIMATE FINENESS OF THE BULLION PRODUCED OVER THE VARIOUS HALF-YEARLY PERIODS DURING WHICH THE DAY DAWN COMPANY WAS IN OPERATION

Half-yearly Periods.	Assay Value of Ore.		Approximate Fineness of Bullion.
	Au. *Dwts.* per Ton.	Ag. *Ozs.* per Ton.	
May–June 1931	13.42	—	—
July–Dec. 1931	20.37	—	—
Jan.–June 1932	23.88	7.52	530?
July–Dec. 1932	14.37	11.66	540
Jan.–June 1933	13.55	15.57	535
July–Dec. 1933	8.37	21.83	529
Jan.–June 1934	8.4	11.18	522
July–Dec. 1934	6.35	6.74	509
Jan.–June 1935	5.27	—	494

GENERAL GEOLOGY.

The basement rock of the Edie Creek area is the Kaindi metamorphic series of schists, slates, phyllites, and limestones, of undetermined but probably pre-Mesozoic age. They are intruded by a series of porphyry bodies that vary slightly in composition but are all of Tertiary, mostly late Tertiary, age. Over most of the Upper Edie area the phyllite and the porphyries have been

subjected to intense hydrothermal alteration, considered to be due to the end products of volcanic activity, and both have been altered to soft decomposed rocks, the phyllite to a chloritoid schist locally known as mudstone. Most of the gold of the rich alluvials of Edie Creek and the extensive placers of the Bulolo River Valley was originally shed from small, rich quartz-gold stringers, rarely more than an inch or two thick and a few feet long, distributed irregularly throughout the hydrothermally altered rocks. Most of the larger lodes, too, which are highly manganiferous ore bodies, with high silver values, occur in this area, along a general northwest-southeast line, immediately to the north of one of the main intrusive porphyry bodies. The Day Dawn lode is the one notable exception to this rule, occurring in comparatively unaltered phyllite on the opposite side of this porphyry mass.

The phyllite is composed mainly of quartz granules and scales of micaceous minerals, chiefly biotite, with a few plagioclase crystals and varying amounts of chlorite, pyrite, titanite, magnetite, ilmenite and rutile. Dips and strikes vary locally but the general average in the vicinity of the Day Dawn lode is fairly consistent, the dip being 35°–45° SW. and the strike 30°–40° NW. Numerous veinlets of secondary quartz are found in the phyllite, some conformable, some cross-cutting. These mostly belong to an earlier epoch of mineralization connected with a large granodiorite batholith that underlies and intrudes the Kaindi series throughout most of the Morobe Goldfield. Secondary pyrite, mostly in small crystals, is particularly abundant in the neighbourhood of the porphyry intrusions and here also the phyllite is generally silicified.

Two main bodies of porphyry outcrop within a short distance of the Day Dawn lode, but are separated by a band of phyllite along Merri Creek so that their time relationship is not known. In their marginal portions the two porphyries appear to be similar, both are very weathered, with a few recognizable products of crystals, quartz, biotite and hornblende, and abundant pyrites. The distinctive character of the two intrusions becomes more apparent away from their boundaries, the northern one being classed as a hornblende, the southern one, with which the Day Dawn lode is

associated, as a quartz-biotite porphyry. Its present composition is largely a reflection of the hydrothermal alteration to which it has been subjected. Only the clear, more or less round quartz crystals have remained unchanged. Biotite, which occurs plentifully in well formed hexagonal crystals, is completely altered to anauxite, feldspars to sericite, and hornblende to leucoxene and other weathered iron products. The ground mass is fine-grained and probably composed mainly of very fine quartz. Magnetite, hematite, and apatite are also present. Pyrite occurs throughout but is especially plentiful near the margins and in the associated lenses. Here, in addition to the abundance of pyrite, the porphyry alters in character to a more homogeneous rock, and phenocrysts of quartz and biotite are smaller or absent. In the neighborhood of the Day Dawn main lode the porphyry dips away from the lode, that is, it underlies to the southwest, at an angle between 40 and 60 degrees.

ORE GEOLOGY.

The Day Dawn lode occupies a zone of fissuring and shearing that is intimately associated with the quartz-biotite porphyry intrusion. For some distance at its south eastern end it follows the contact of the porphyry and the phyllite. Along the lode's central portion, after leaving the contact, the fissure is well defined and cuts across the structure of the phyllite. In the outer portion the lode becomes less definite and conforms more and more to the strike and dip of the enclosing beds, the walls become less distinct, and the limits of mineralization are harder to determine. The orientation of the lode, therefore, varies and dips range from 35° to 90°. The strike where the lode is in contact with the porphyry averages N. 50° to 65° W. and the dip is about 75 degrees in the lower levels and 50 degrees above the " B " level. In the central portion, the strike is N. 22° W. and the dip is 63° to 75° with a slight flattening towards the surface. The direction of the outer portion of the lode is about N. 45° W. and dip is below 60 degrees and becomes progressively less (Fig. 2).

The lode is composed of a series of small quartz veins and stringers and sheared and broken phyllite, with varying amounts

of black manganese oxide. The quartz veins, which are seldom more than an inch or two thick and a few feet long, generally conform roughly to the direction of the lode, although in places

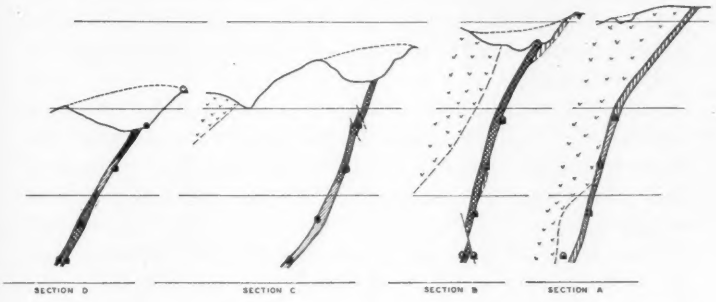

FIG. 2. Cross-sections through the lode, showing the porphyry retreating from the hanging-wall and the general flattening of the dip of the lode away from the porphyry contact. Legend is the same as for Fig. 3.

they may cut across it. The proportion of manganese varies, and in the inner portion of the lode, corresponding fairly closely to the extent over which it occupies the porphyry-phyllite contact, it is mainly composed of soft black manganiferous material. In the outer portion manganese is correspondingly less abundant and the lode is largely soft thin-bedded phyllite with conformable quartz veins. Silicified bands occur within the lode or, more commonly, along a hanging wall, and in places the lode is irregularly silicified over its entire width. Brecciation also is of common occurrence, in places associated with the more highly mineralized sections in the upper levels. On the intermediate level at the south eastern end, a large area of brecciation affects the wall as well as the lode.

The normal width of the lode is between 3 and 4 feet. The average of 320 samples taken on the levels during development, presumably across the full width of mineralization, is 45 inches. Locally, the width may vary from 12 inches to 8 feet and in one place a twenty-foot width of ore was stoped for some time. Va-

riations in the width may be due to widening of the fissure that forms the lode channel, or to mineralization extending into adjoining beds; in many places the walls are not well defined. On the surface, for instance, towards the southeast end of the open cut, the footwall for a width up to 20 feet consists of soft manganiferous mineralized beds that carry a few pennyweights of gold to the ton.

The lode extends throughout the total length of the "B" level and the No. 1 level, respectively 568 and 600 feet, although the whole length does not carry payable ore. On the Intermediate level the lode has been explored for 780 feet and on No. 2 level for 430 feet.

Faulting.—Minor faulting is exceedingly abundant throughout the workings, and over one hundred faults were mapped on the four levels alone. About an equal number each of normal and reverse faults were observed, but of those affecting the lode perhaps the majority are normal faults. Maximum displacement found is 49 feet where the lode on No. 2 level is affected by a fault series. Displacement on most of the faults is only a few feet. Faults are not consistent; they are mostly divided into several branches, and do not persist far in any direction. The fault, for instance, which displaces the lode 49 feet on No. 2 level, is hardly recognizable on the intermediate level fifty feet higher. The faults are marked, particularly on the lower levels, by water dripping from the back of the drift. Since most of the faults displace the lode and also have no appreciable influence on the values, it is assumed that they are later than the mineralization. There is no doubt, however, that some faulting preceded mineralization, as is to be expected so close to an intrusive porphyry mass, and a certain amount of faulting was associated with the formation of the fissure in which the lode was deposited.

Faults underground fall mainly into two classes, one series of strike faults more or less parallel to the general direction of the lode and another series that cut the lode transversely, commonly at right angles. In all cases the dips are fairly steep, almost without exception greater than fifty degrees, and in the first class the

faults commonly dip in the opposite direction to the beds. If any distinction can be made, it may be said that amongst the strike faults reverse faults predominate, while perhaps the majority of the other class are normal faults. Most of the faults have associated with them irregular areas of secondary silicification, accompanied often by pyrite, caused by later solutions passing along them.

Genesis of the Lode.—The Day Dawn lode is characteristic of an ore deposit formed at fairly shallow depth below the surface. The origin of both the lode channel and the lode is intimately connected with the quartz-biotite porphyry intrusion. The fact that the course of the lode, after leaving the contact of the porphyry and the phyllite, first cuts definitely across the strike and later turns to conform with the strike and finally also with the dip of the phyllite strongly suggests that the fissuring was a direct result of the displacing forces due to the intrusion of the porphyry into the older rocks. With increased distance from the source of these forces, the fissuring died out and become merged in the shear planes of the phyllite.

The mineral-bearing solutions that have given rise to the lode originated in the magma that has produced the quartz-biotite porphyry. After the intrusion of the porphyry and the formation of the lode fissure, the gangue and ore minerals were deposited from these solutions ascending along the porphyry-phyllite contact and the adjacent fissuring. The principal deposition of quartz, pyrite and gold has taken place in the central portion of the lode, and these minerals persist to a point where the fissuring has almost died out, and then the values apparently disappear. A certain amount of the original manganese minerals, mostly carbonates, were also deposited in the central portion of the lode, but their main concentration, together with some gold, was along the contact of the phyllite and porphyry.

Within the lode on No. 2 level, where unoxidized ore is exposed, the only minerals recognized were quartz and pyrite, and some manganite in the concentrates. In a parallel smaller lode just within the porphyry on the Intermediate level, about 30 feet

from the main lode, a more complete succession of minerals is found in ore with a more or less banded structure. Most of the minerals were deposited in cavities or along partly open faces, and the quartz and calcite in particular commonly show a succession of very thin layers due to repeated depositions. The minerals recognized, in their order of deposition, are: quartz, pyrite, quartz, pyrite, rhodocrosite, chalcopyrite, galena?, calcite, pyrargyrite, proustite, stephanite, calcite. Flakes of native silver were found in open cracks in the phyllite of the lode not very far away on the same level. It is interesting to note that in unoxidized ore from one of New Guinea Goldfields lodes on the southern side of the quartz-biotite porphyry, J. D. H. Donnay [1] established the following mineral sequence:—quartz, pyrite, sphalerite, tetrahedrite, chalcopyrite, galena, calcite, stephanite, chalcopyrite.

Gold Occurrence and Distribution.—The gold occurs free and, in all observed cases, closely associated with the quartz veins. It is commonly distributed in bands of varying richness roughly parallel to the sides of the massive quartz of the stringers, or it may be associated with quartz crystals in vugs. Except at the outcrop and occasional rich patches in the upper levels, gold is not generally visible. In the open cut, rich specimens of quartz adhering to phyllite have been collected. Average fineness of the gold bullion is 522.5

The best guide to values in the lode underground is the presence of a sugary type of quartz. No marked favourable relation between the gold and the manganese content of the lode can be observed. Although manganese is present throughout the lode, it becomes pre-dominant only where the lode follows the porphyry-phyllite contact, and this portion of the lode carries much lower gold values. Pyrite, mostly very fine-grained, although in a few places coarsely crystalline, or its oxidation products, is plentiful throughout the lode and also in the country rock particularly at or near the contacts of the phyllite with the main porphyry body or the small porphyry lenses. In view of this wide distribution

[1] Donnay, J. D. H.: Report on rock and ore specimens for New Guinea Goldfields Ltd. Made available by courtesy of the Company.

of the pyrite it is difficult to determine any original relationship between the pyrite and the gold content of the lode, though a certain amount of the gold on No. 2 level is definitely associated with pyrite.

The length of payable ore on the various levels is as follows. Anything over about 7 dwts. Au. per ton is taken to be payable, though this figure is fairly arbitrary.

"B" level	360 feet
No. 1 level	600 feet
Intermediate level	625 feet
No. 2 level	165 feet and 36 feet.

In the two upper levels the ore is bounded by the surface of the hillside, but on the Intermediate and the No. 2 levels the lode dies away at the end remote from the porphyry. The falling off in values at the inner or southeastern end of the lode is gradual and shows a rough correspondence with the porphyry contact on the lode's hanging-wall. The best values decrease short of the contact, but ore of lower although still commercial grade continues for some distance along the contact, finally falling off to less than 5 dwts. per ton. Apparently the gold-bearing solutions emanated from the porphyry boundary and met conditions more favourable for gold and quartz deposition in the fissure in the phyllite. Gold continued to be deposited throughout the total length of the fissure and perhaps for some further distance along the bedding of the phyllite. Distribution of values is naturally locally irregular, but generally fairly uniform, considering that the presence of gold depends mainly on the numerous quartz stringers, each individual one of each may vary in gold content.

The ore shoot divides into two portions between the Intermediate and No. 2 levels, so that on the lower level there are two disconnected sections with payable values. The longitudinal sections (Fig. 3) show clearly the distribution of values as determined by all the available records of the mine. It should be noted that they probably represent a slightly optimistic view of the values in the earlier workings since many of these assay records are in shillings, showing only the combined value of the gold and silver content. Consequently it is not known how much of the stated value is gold and how much silver.

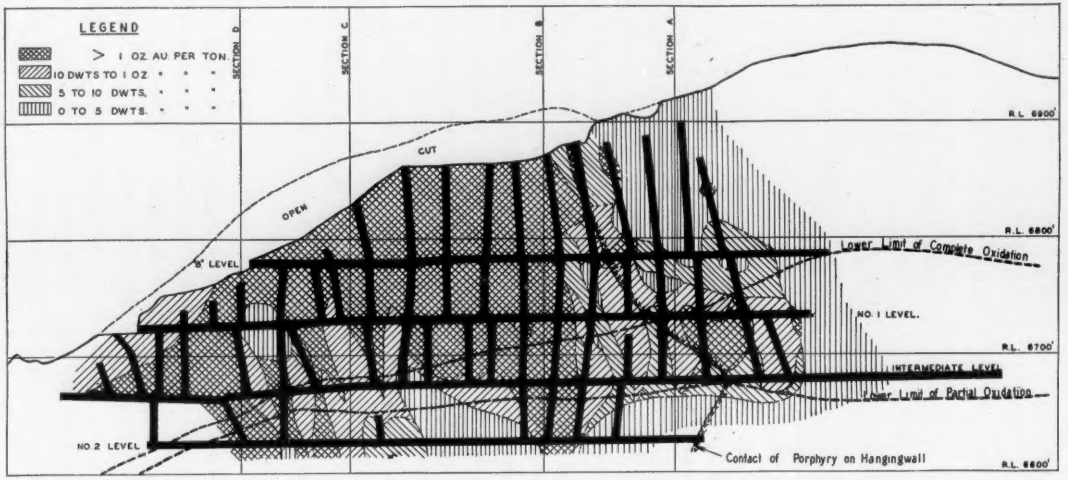

FIG. 3*a*. Longitudinal sections of the Day Dawn Lode, showing distribution of values and their relation to porphyry on the hanging-wall, and to the depth of oxidation.

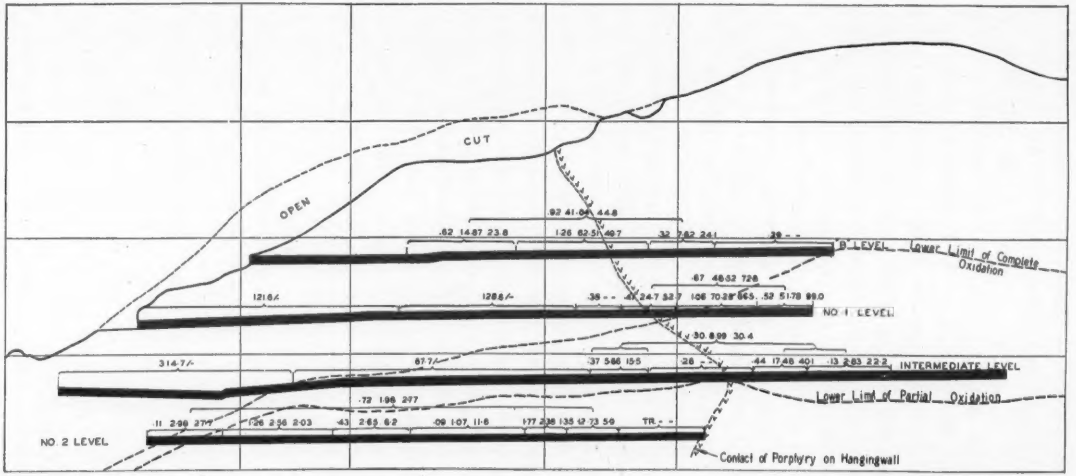

FIG. 3*b* indicates, from left to right, i. Average gold content in ounces per ton; ii. Average silver content in ounces per ton; iii. Silver/gold ratio. Values shown in shillings are earlier records figured with gold at 85/– and silver 1/6 per oz. Individual gold and silver returns for these sections are not available.

Distribution of Silver.—The silver content of the lode is much higher than the gold and the average of 193 samples from the various levels is 19.185 ounces, while the gold content of the same samples averages only 13.029 dwts., the proportion of gold to silver being about 1 to 29.5. Unfortunately, since the earlier mine samples were recorded in shillings, calculated on the basis of gold at 85/– per fine ounce and silver at 1/6d. per ounce, comparisons and individual silver and gold values are unobtainable over a considerable portion of the mine. The upper levels are much higher in silver than the two lower levels, and the distribution of silver appears to vary according to several factors, the main ones being: 1, distance from the surface; 2, distance from the porphyry contact; 3, the gold content of the lode. With regard to 1., there is a rather poorer zone near the surface, probably due to leaching of silver, and the values increase to a maximum on No. 1 level. Then the values decline rapidly and on No. 2 level the assays are constant in the neighbourhood of 2 ozs. per ton, which most likely represents the primary value of the ore.

Reference to Fig. 3 indicates clearly the dependence of the silver values on the position of the porphyry contact, which also governs the relative quantities of manganese in the lode, for in all levels, except No. 2, the highest values, as well as the highest silver-gold ratio, are seen to lie just inside the contact. These high silver values correspond to that portion of the lode which, though lower in gold than the outer portion, still carries commercial ore and also is strongly manganiferous. Thus, the silver values here reflect both the manganese content of the lode and the original intensity of mineralization as determined by the gold values. The first factor decreases away from the contact and the second decreases in the opposite direction.

The three main factors, then, which govern the distribution of silver values, are seen to be dependent on other conditions. The variation of values with depth from the surface is largely the result of solution and secondary enrichment, and the lower value of the primary ore. The influence of the distance from the porphyry contact is really the influence of the manganese content

of the lode, and the relation to the gold values is governed by the strength of the primary mineralization and by the occurrence of silver alloyed with the gold.

Silver content of the bullion produced averages between 470 and 480 parts per 1,000 and represents a recovery of 1 per cent to 15 per cent of the head value. It seems certain that almost all of this is supplied by the natural constitution of the gold, which occurs as an alloy-electrum, 500 to 550 fine, corresponding to the grade of the alluvial gold of the district. A very small amount only of other silver minerals may also have been recovered by the amalgamating action of the mercury in the mill, or in the concentrates from the blankets over which the tailings passed before being discharged. The exceedingly small quantity of these silver minerals, stephanite, pyrargyrite, etc., that has been observed in the mine, and that in one place only, makes it unlikely that they contribute largely to the silver content of the ore. Recent work [2] on manganiferous silver ores has practically established that at low temperatures in a reducing environment a silver manganite is formed, which is insoluble in all normal solvents for silver, such as cyanide and acids, and which is very difficult to treat. It is highly probable then, that most of the silver present is in the form of this insoluble manganite, an assumption that is supported by the association of the highest silver values with the most manganiferous portion of the lode.

Secondary Enrichment.—The available data on supergene sulphide enrichment are not definitely conclusive but throw interesting light on the distribution of the values. Conditions are chemically suited to solution of gold and silver—mine waters in all cases are acidic, some strongly so, and some samples give positive manganese reactions. On the other hand surface erosion has been rapid, and solution and transportation of gold have certainly lagged behind the removal of the outcrop by denudation. The lower silver values near the surface, however, indicate either that silver has been removed from this area or that the higher values about No. 1 level represents a temporary halt in the continuity of the lowering of the water level corresponding to surface erosion.

[2] Caron and Clavenger: Treatment of manganese silver ores.

The different character of the gold at and near the out-crop, where so much visible free gold occurs, from that on No. 2 level, is evidence that the gold has undergone solution and redeposition and the comparatively low values on No. 2 level appear to indicate that enrichment has accompanied the process. The fineness of the gold shows a general diminution since the commencement of milling operations from about 546 to 490. This is taken to be a reflection of the gradually greater depth from the surface of the average ore mined and is explained on the theory that the upper portion of the lode contains quantities of secondarily deposited gold, which would be expected to be of higher grade than the primary mineral. (Refer to Table 1.)

The lower limit of *complete* oxidation of the country rock is about 165 feet below the surface of the higher ground and approaches the surface in the lower areas so that at the bottom of the Merri the phyllite of the creek bed is almost completely unoxidized. The limit of partial oxidation, corresponding to the permanent water level varies from 16 to 99 feet lower down. In all cases the lode itself is oxidized to a slightly lower level than the country rock, due to the easier passage of the solutions. The lower limit of partial oxidation will be seen on the longitudinal section to correspond fairly closely to the bottom of the higher values within the lode, while the higher silver values occur mostly above the lower limit of complete oxidation. Certain other factors are to be taken into consideration on the question of deciding how great an influence secondary enrichment has had on the distribution of values in the lode. Passage of solutions in the upper portions of the mine is by no means restricted to the lode channel but circulation is fairly general along bedding planes, faults and fissures in the rock. Moreover, faults in and across the lode are always avenues of water circulation, but do not appear to have any connection with the gold values. In other parts of the world lodes of similar type and origin to the Day Dawn are notorious for the presence of primary ore shoots, and it is just possible that the higher values in the upper levels may be largely, though certainly not entirely, of primary origin.

With regard to silver values, there is no doubt that secondary enrichment has played a large part in their arrangement within the lode. Repeated leaching from near the surface and deposition at or near water level have been responsible for the high values above the Intermediate level. On this level itself the silver has been slightly augmented in the inner portion and probably much more so in the outer portion. The silver content throughout the No. 2 level is constant at about two ounces per ton, with only a slight correspondence to the gold content. This seems to represent the primary silver value of the lode on this level, though portions of it elsewhere may have originally been richer.

CONCLUSION.

It is unfortunate that no exploration work was done below the No. 2 level, so that more definite information could have been obtained on the character and value of the ore below this horizon. Exhaustion of the ore above this level and the alarming decrease in gold values with increased depth caused the mine to be closed down without initiating any deeper exploration. Experience in depth at other mines in the vicinity has always shown the primary ore to be of much lower grade than the upper oxidized portions and seldom workable. Taking this into consideration and the various factors enumerated above governing the distribution of the gold it seems most likely that payable ore would not continue far below the No. 2 level.

DEPARTMENT OF MINES, WAU,
Territory of NEW GUINEA,
December 6, 1938.

ORIGIN OF THE SWEETWATER, TENNESSEE, BARITE DEPOSITS.[1]

ROBERT A. LAURENCE.

The Sweetwater residual barite deposits are underlain by irregular fissure-veins in Beekmantown (Knox) dolomite. The veins are associated with dolomitized limestone. Calcite, pyrite, fluorite, and barite are the only common minerals of these deposits and were deposited in that order. Deposition from ascending thermal waters is indicated.

INTRODUCTION.

THE Sweetwater district, in Monroe, McMinn, and Loudon Counties, East Tennessee (Fig. 6), is Tennessee's leading barite-producing area. About 600,000 tons have been produced from residual deposits in this district, and at the present time there are six producing and twenty-seven abandoned mines.[2] The regional geology has been mapped by Arthur Keith in the Loudon and Kingston folios. The area contains several blocks of Knox dolomite and other early Paleozoic sedimentary rocks, bounded by southeast-dipping thrust faults. The barite deposits of the district have been described by Gordon[3] who noted that the deposits were found in three parallel "veins" or "leads" following the strike of the Knox dolomite in three different fault blocks. The mineralogy of these deposits has been discussed briefly by Secrist.[4] Pinnacles or "midribs" of bedrock, containing vein and breccia deposits have been encountered in a few mines (Fig. 1). The residual deposits consist of nodules of barite in a clay matrix, and

[1] Published by permission of the Director, United States Geological Survey and the Tennessee Valley Authority. Presented before the Society of Economic Geologists, Knoxville Meeting, Oct. 6, 1938.

[2] Penhallegon, W. J.: Barite in the Tennessee Valley region. T. V. A., Geol. Bull. 9: 10, 1938.

[3] Gordon, C. H.: Barite deposits of the Sweetwater district, east Tennessee. Tenn. Geol. Surv., Resources of Tennessee, 8: 48–82, 1918.

[4] Secrist, M. H.: Zinc deposits of east Tennessee. Tenn. Div. Geol. Bull. 31: 133–134, 1924.

have been concentrated by weathering and removal of the soluble wall rock material. Because of their lack of commercial interest, the vein deposits have received little attention, but they present certain interesting features bearing upon the origin of the deposits, and it is with these that the present paper deals.

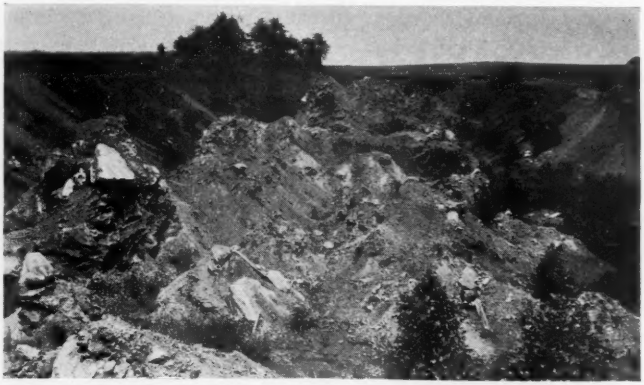

FIG. 1. View of Ballard (Krebs) barite mine, Sweetwater district, showing bedrock pinnacles. (Photo by W. J. Penhallegon.)

This paper is the result of two weeks' field work by the writer, assisted by L. J. Mueller and N. A. Rose, in 1934, under the direction of Dr. L. W. Currier of the United States Geological Survey, in connection with a survey of the zinc and lead deposits of Tennessee. Further work, including more detailed studies of the vein deposits, has been completed by the writer in connection with studies of mineral resources for the Geologic Division, Tennessee Valley Authority.

DESCRIPTION OF THE PINNACLES.

The writer has observed bedrock pinnacles in five mines in the district, but in only one, the Ballard (Krebs) Mine, five miles east of Sweetwater, are the vein deposits well enough exposed for study (Fig. 1). All descriptions in this paper refer to this mine.

Three types of rock are found: dense blue limestone, finely crystalline dolomite, and coarsely crystalline dolomite. Fossils in the limestone beds indicate that they belong to the Beekmantown ("Post-Nittany") portion of the Knox dolomite.

Although in general the rocks of the pinnacles conform to the regional strike of N. 45° E., the detailed structure is so complex, and so confused by slumping, that it is not practicable to map the structure on any convenient scale. The strike varies between N. 75° W. and N. 60° E., with dips mostly to the southeast. The most common strikes, however, are between N. 30° E. and 50° E. The long axis of the pit as well as the line of the "midrib" is N. 35° E. Joints trending in nearly every direction are present, but they appear to be grouped into three main sets: N. 40–55° E., N. 15–25° E., and N. 25–45° W. In many other places in this general area, similar localized intense deformation has been found to be related to nearby thrust faults. Although no other evidence of such faults has been observed here, it is not unlikely that they may exist. The nearest known thrust faults are three miles southeast (3,500 feet higher stratigraphically) and two and one-half miles northwest (3,000 feet lower stratigraphically). The alignment of all the barite deposits of the district along a definite strike line suggests that the shattering and brecciation were restricted to certain favorable beds and are not necessarily related to any particular faults. The tectonic origin of the zinc-ore breccias of the Southern Appalachians has been conclusively demonstrated by Currier.[5] The writer believes that the field evidence clearly shows a similar origin for the shattering and brecciation in the Sweetwater district and that the suggestion that they may have originated through cavern collapse cannot be supported.

DESCRIPTION OF THE VEINS.

The veins occupy joints and bedding planes and are as irregular in their strike and dip as the enclosing structures.

[5] Currier, L. W.: Structural relations of southern Appalachian zinc deposits. ECON. GEOL., 30: 282, 1935; also Zinc and lead region of southwestern Virginia. Va. Geol. Surv. Bull. 43: 84–88, 1935.

There are no large, persistent veins. Generally less than four inches in width, they commonly expand at intersections into large irregularly shaped masses, and elsewhere thin into mere stringers, or pinch out. The contact between vein and wall is commonly sharp, but in the present weathered condition of the pinnacles, it is difficult to obtain samples of the vein matter with any of the wall rock adhering.

Primary vein minerals are calcite, pyrite, fluorite, barite, sphalerite, and galena. Barite is by far the most abundant mineral, but both pyrite and fluorite are present in many veins that do not contain barite. Calcite is not common, and sphalerite and galena are only sparingly present. The veins are simple fissure-fillings, and exhibit typical crustified banding (Fig. 4). Except for the possibility of some replacement of fluorite by barite, there is no evidence of replacement in the relations of any of the vein minerals. The typical veins have a band of barite in the middle, with bands of fluorite on each side of it, and bands of pyrite at each of the vein walls.[6] In some veins there are open spaces along the middle. They are most common in those veins that contain only pyrite and fluorite.

The barite is commonly white or colorless but some is dull gray. It is generally in interlocking, radiating crystals, and there are some rosettes. Few good crystals have been formed. This feature is in direct contrast to the barite deposits of the Fall Branch district of upper East Tennessee, and those of Cocke County, where well-formed crystals several inches on a side are common.[7] Fluorite is green, colorless, or purple, and both its position in the vein and its microscopic relations indicate that most of it is earlier than the barite. Fig. 2 shows the contact of fluorite and barite in a vein and indicates that the barite was deposited upon a well-formed fluorite cube. In many thin sections of the veins, minute veinlets of barite can be seen on the cleavage planes of fluorite crystals. However, some fluorite is undoubtedly later

[6] In a brief summary published in an earlier paper (A. I. M. E., Tech. Pub. 880) the writer inadvertently misstated this order, with reference to fluorite and barite, and herewith makes the correction.

[7] Laurence, R. A.: Black barite deposits in upper east Tennessee. Jour. Tenn. Acad. Sci., 13: 192–197, 1938.

than barite, as there are a few veinlets that cut directly across barite. There is some evidence that all the purple fluorite belongs to this later period, as it is the most common variety observed in this relation. In many veins with open centers, there

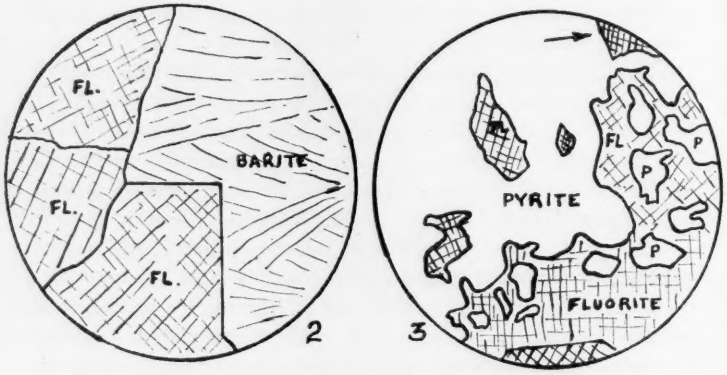

FIG. 2. Sketch of thin-section showing radiating crystals of barite in sharp contact with previously formed fluorite cube. × 20.

FIG. 3. Sketch of thin-section showing fluorite surrounding small "islands" of pyrite. Note that octahedral cleavage planes of fluorite make angles of 20° and 70° with cube face of pyrite in northeast quadrant. × 20.

are well-formed cubes of purple fluorite, less than an inch on a side. Calcite is generally found in veins that do not contain the other minerals, but some stringers of fluorite cut across calcite veins. Calcite is thought to be the earliest of the vein minerals.

Pyrite is the only common sulphide mineral of the veins. Its position in the veins, and the occurrence of both fluorite and barite in cracks in pyrite, and surrounding small "islands" of it (Fig. 3) indicate that it preceded both. The only sphalerite seen by the writer is of the light yellow variety, and occurs as narrow veins between pyrite and fluorite (Fig. 4) and as small "islands" in both barite and fluorite. Galena is almost non-existent in these deposits.

Thus, the paragenetic sequence of the minerals is as follows: calcite, pyrite, sphalerite and galena, fluorite, barite, (purple fluorite?). All of the minerals, with the possible exception of

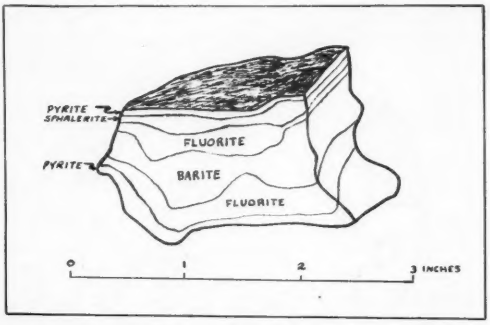

FIG. 4. Sketch of a fragment of the vein filling, showing banding. Except for the presence of sphalerite, this represents a typical vein.

some of the calcite, belong essentially to one period of mineralization.

RELATIONS TO COUNTRY ROCK.

There are no important veins in the limestone, and a relatively small number in the finely crystalline dolomite, the type of dolomite here considered to be an "original," or sedimentary, dolomite. There are a few thin stringers of fluorite and barite in chert, but by far the majority of the veins are in the coarsely crystalline dolomite. This rock has been produced by alteration and recrystallization of the limestone. Beds of limestone in some of the pinnacles grade vertically and horizontally into the coarsely crystalline dolomite, with intermediate zones in which there are euhedral crystals of dolomite embedded in a matrix of dense or very finely crystalline limestone (Fig. 5). This same type of recrystallized dolomite commonly accompanies the vein deposits in the Fall Branch district, upper East Tennessee,[8] but it should be stated that it is also found at many unmineralized localities in East Tennessee.

[8] Secrist, M. H.: Op. cit., p. 99.

As stated above, the contacts of veins and wallrock are quite clear and sharp. There is no evidence of replacement of wallrock by any of the vein minerals. The writer has seen no fragments of wallrock included in the vein matter.

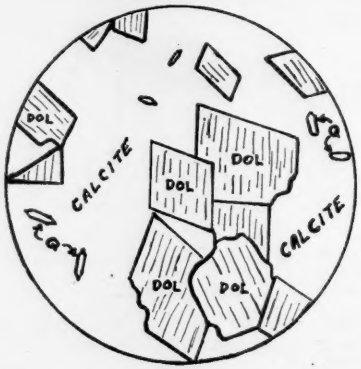

FIG. 5. Sketch of a thin-section showing dense limestone partially replaced by euhedral crystals of dolomite. Q = quartz. × 50.

Igneous rocks are not known in the Sweetwater district. The nearest post-Ordovician igneous rocks are some of the granites of the Blue Ridge region, and a small basic intrusive body in Union County, Tennessee,[9] sixty miles north of Sweetwater.

DISTRIBUTION OF THE MINERALS.

The vertical range exposed is too small to indicate whether there is any vertical zoning of the minerals in these deposits. The weathered condition and limited lateral extent of the pinnacles also prevent any conclusions as to horizontal zoning within any one deposit.

However, considering the Sweetwater district as a whole, there is a rather distinct suggestion of zoning, with barite in the central area and zinc in the outlying areas (Fig. 6–*A*). This same relationship exists, but is less distinct, in the Fall Branch

[9] Hall, G. M., and Amick, H. C.: Mica peridotite in Tennessee. Am. Mineral., 20: 204, 1935.

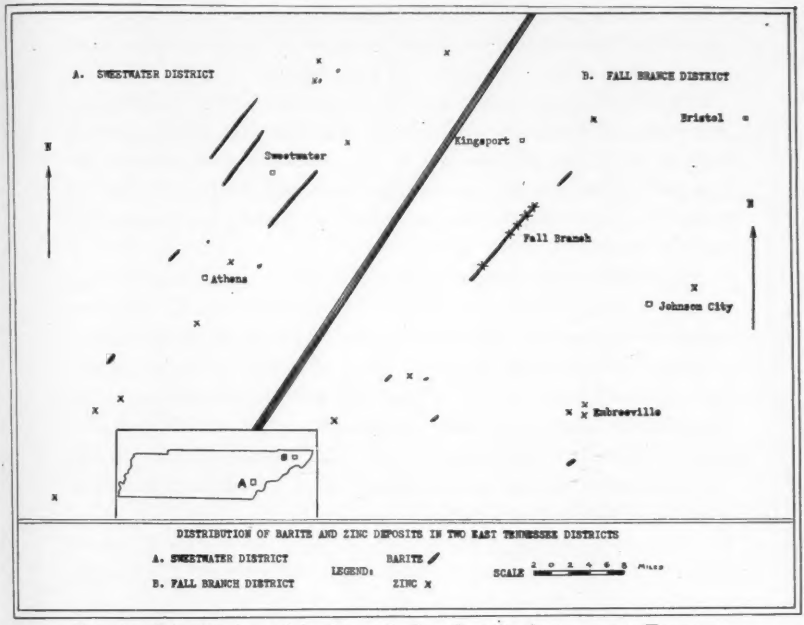

FIG. 6. Distribution of barite and zinc deposits in two east Tennessee districts.

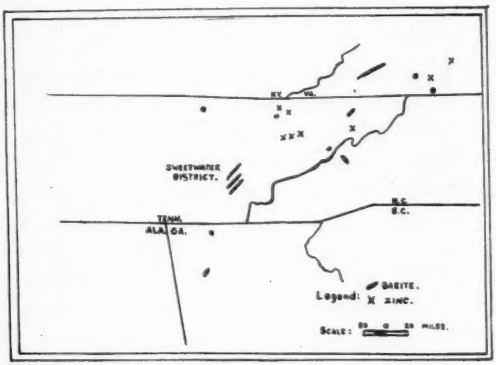

FIG. 7. Map showing distribution of major barite and zinc deposits in Tennessee and adjacent states.

district (Fig. 6–*B*). If East Tennessee and adjacent areas are considered as one large region, however, just the reverse areal relationship exists (Fig. 7). If the map were extended a little farther north, some additional barite deposits would complete the zone around the southwest Virginia zinc deposits. This apparent zoning is further complicated by the fact that some fluorite accompanies the central zinc zone in southwest Virginia,[10] but the only prominent fluorite deposits in East Tennessee are in the outer zone of barite.

The difficulty in interpreting any of these areal relationships lies in defining the limits of any one district. Thus, the most northerly deposits in Fig. 6–*A*, might equally well be considered as outlying deposits of the Mascot zinc district. Also, any direct relationship between the Fall Branch barite-zinc deposits and the Embreeville zinc-lead deposits is extremely doubtful. It is doubtful if the areal relationships are of any real significance to the problem, and certainly any interpretation of the large-scale zoning must be considered unreliable.

COMPARISON WITH OTHER DISTRICTS.

In southwest Virginia, barite deposits occur in limestones and dolomites of Beekmantown age. They are principally fissure veins and breccia deposits. Although the minerals are nearly contemporaneous, the order of deposition is pyrite, fluorite, barite, calcite.[11]

Barite veins in western North Carolina occur in granites and quartzites. According to Stuckey and Davis, deposition of sulphides (especially pyrite) followed silicification of the wallrock, and was followed by deposition of fluorite and barite, as contemporaneous minerals, the fluorite later giving way to barite.[12] This district extends into Cocke County, Tennessee, where sev-

[10] Currier, L. W.: Structural relations of southern Appalachian zinc deposits, ECON. GEOL., 30: 285, 1935.

[11] Edmundson, R. S.: Barite deposits of Virginia. A. I. M. E. Tech. Pub. 725, 1936.

[12] Stuckey, J. L. and Davis, H. T.: Barite deposits in North Carolina. Trans. A. I. M. E., 115: 346–355, 1935.

eral large barite veins occur in Cambrian quartzites. The writer has seen two barite veins associated with quartz veins in granite in Unicoi County, Tennessee.

In the veins of central Kentucky, the sulphides—chiefly sphalerite and galena—followed deposition of barite and fluorite.[13] This reverse order is explained by Robinson as due to a later rise in temperature during vein deposition. The veins are fissure-fillings in Ordovician limestone, and are much larger and more continuous than those of the Sweetwater district. Dolomitization is not reported. Similar veins occur in Ordovician limestones at several localities in Middle Tennessee.

The Missouri deposits are fissure veins and breccia deposits, mainly in dolomites, and were deposited in this order: pyrite, galena and sphalerite, barite.[14]

The Cartersville, Georgia district contains some replacement bodies in addition to vein and breccia deposits.[15] Some small deposits with fluorite occur in Alabama.

By comparison with these deposits, it is apparent that the Sweetwater deposits are of the same type as the other leading barite deposits of the Southern Appalachians and adjacent areas. Most recent students of these deposits have ascribed their origin to magmatic waters.

SUMMARY AND CONCLUSIONS.

The Sweetwater barite deposits are of the simple fissure-filling type. They occur in shattered zones of Beekmantown limestone and dolomite which grade into "crackle breccia," and are closely associated with dolomitized limestone. The enclosing structures were formed during the Appalachian revolution. There is an apparent though obscure zoning of barite and zinc deposits. Igneous rocks are not known in the district.

Comparison with other barite deposits in the Southern Appalachians indicates similarity of mineral associations, paragenesis,

[13] Robinson, L. C.: The vein deposits of central Kentucky. Ky. Geol. Surv., Series 6, vol. 41, 1931.

[14] Tarr, W. A.: Barite deposits of Missouri, ECON. GEOL., 14: 46–67, 1919.

[15] Hull, J. P. D.: Barytes deposits of Georgia. Ga. Geol. Surv. Bull. 36, 1920.

and structural features. Most recent writers consider these other deposits to be of magmatic origin.

Available data in this district are limited to a few mines and are inconclusive as to the origin of the vein deposits. They appear to have been formed by ascending thermal waters, but whether these were magmatic or meteoric remains in doubt.

TENNESSEE VALLEY AUTHORITY,
KNOXVILLE, TENNESSEE,
November 15, 1938.

RUBY GULCH GOLD MINING DISTRICT, LITTLE ROCKY MOUNTAINS, MONTANA.

J. L. DYSON.

ABSTRACT.

In the Little Rocky Mountains, porphyry intrudes Pre-Cambrian metamorphic rocks and overlying sedimentary rocks, with large roof pendants of Pre-Cambrian rocks projecting downward into the porphyry mass. A series of very high-angle faults radiate from the central part of the uplift. Hydrothermal solutions rising along these faults have deposited gold and other minerals, giving rise to epithermal deposits.

The ore deposits, which are worked primarily for gold, are mostly of low grade. In the ore zones, quartz is the most abundant mineral although pyrite, the only sulphide noted, is common. Fluorite is locally common close to the faults. Some relatively high grade ore consists of a mixture of quartz, pyrite, fluorite, gold and sylvanite.

INTRODUCTION.

RUBY Gulch is one of two important gold mining camps in the Little Rocky Mountains. This mountain uplift, in the southwestern part of Phillips County, Montana measures about ten miles in its greatest dimension, and has been the center of varied gold mining activity since the discovery of auriferous placers in 1884.

The most important lode deposits are mainly of low grade and have been deposited along faults in porphyry that has intruded Pre-Cambrian metamorphic rocks. W. H. Emmons [1] stated that the ores were probably deposited by ascending waters. Corry [2] expressed the opinion that gold and associated minerals were products of the final phase of vulcanism and were deposited in the shallow facies represented by the porphyry. The writer, after a field and petrographic study, agrees in general with Corry and be-

[1] Emmons, W. H.: Gold deposits of the Little Rocky Mountains, Montana. U. S. Geol. Surv. Bull. 340: 109, 1908.

[2] Corry, Andrew V.: Some gold deposits of Broadwater, Beaverhead, Phillips, and Fergus Counties, Montana. Montana Bur. Mines and Geol., Mem. No. 10, 1933.

lieves that the Ruby Gulch ores were deposited by ascending hydrothermal solutions under conditions characteristic of the epithermal zone of ore formation. The ores, which are worked chiefly for their gold content, also yield a small amount of silver.

In the early days of mining in the region placers were productive, but evidently are now exhausted.

At present, mining activities in the Ruby Gulch area are confined mainly to two mines, the Alabama in the Alabama fault zone, and the Ruby which is in the Ruby fault zone. Both of these mines have reached depths of 600 feet below the surface.

REGIONAL GEOLOGY.

The Little Rocky Mountains, one of several similar mountain uplifts rising above the Montana plains, were formed by the doming of overlying sediments as the result of intrusions of syenite porphyry during Tertiary time. Most of these sedimentary rocks have now been eroded from the crest of the range.

The oldest rocks of the district are Pre-Cambrian gneisses and schists and are mostly exposed throughout the interior of the uplift. In the Ruby Gulch area these rocks consist of (1) fine-grained, black amphibole schist, the most common rock; (2) finely-banded white gneiss; (3) a rock which has been referred to as a sheared granite-gneiss by Corry [3] and as a pink gneiss with sheared and elongated feldspar crystals by Weed and Pirsson; [4] (4) mica- and garnet-schists; and (5) interbedded hornblende schists and white quartzites with rounded grains. The relationship of the last two rocks to each other indicates a sedimentary origin for the schists as well as for the quartzites of the series. The intrusive nature of the granite-gneiss is shown by the fact that it contains numerous inclusions of the schist.

Overlying these oldest rocks is a series of sediments ranging from the Lower Cambrian Deadwood Formation [5] to the Upper

[3] *Op. cit.*

[4] Weed, W. H., and Pirsson, L. V.: The geology of the Little Rocky Mountains. Jour. Geol., 4: 399–428, 1896.

[5] Collier, A. J., and Cathcart, S. H.: Possibility of finding oil in laccolithic domes south of the Little Rocky Mountains, Montana. U. S. Geol. Surv. Bull. 736–F: 171–178, 1923.

Cretaceous, and all of these rocks show the doming effect of the intruded porphyry.

At places the contact between the porphyry and overlying sediments is marked by the base of the Deadwood Formation although locally the intrusive has extended into younger rocks. In several localities, dikes, which appear to be offshoots from the main porphyry mass, intersect the Kootenai Formation of Lower Cretaceous age.

INTRUSIVE ROCKS.

General Features.—Weed and Pirsson [6] have called the intrusive mass of the Little Rocky Mountains a simple laccolithic body, intruded between the sediments and underlying metamorphics. Later investigators have generally concurred in the opinion that the mass is a laccolith, although Emmons [7] noted that in certain localities, the contact between the porphyry and metamorphic rocks, suggested cross-cutting relations. Collier and Cathcart [8] expressed the opinion that the relative elevation of the mountains is the result of laccolithic intrusion but thought that there were large igneous rock bodies beneath the schist as indicated by the height of some of the schist outcrops on the mountains.

At several places where the top of the intrusive can be observed, it appears to be more or less concordant with the overlying sediments. At other places, however, sediments directly overlie schists, indicating that the intruded porphyry has not apparently everywhere spread out between the Pre-Cambrian rocks and the sediments in true laccolithic manner. Hornblende schist can be found outcropping near the summits of some of the highest peaks of the range (Fig. 1). These outcrops lie high above adjacent porphyry masses, and are of course considerably higher than the sediments of the surrounding plains; this means that the schist has been much elevated, probably by intrusion of the porphyry, an indication that a large porphyry mass underlies the metamorphic rocks.

[6] *Op. cit.*, p. 402.
[7] *Op cit.*, p. 102.
[8] *Op. cit.*, p. 175.

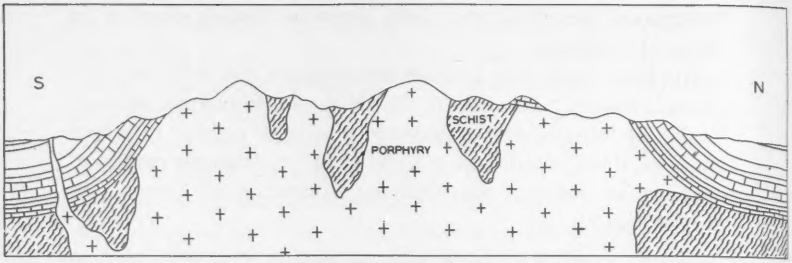

FIG. 1. Idealized cross-section of the Little Rocky Mountains.

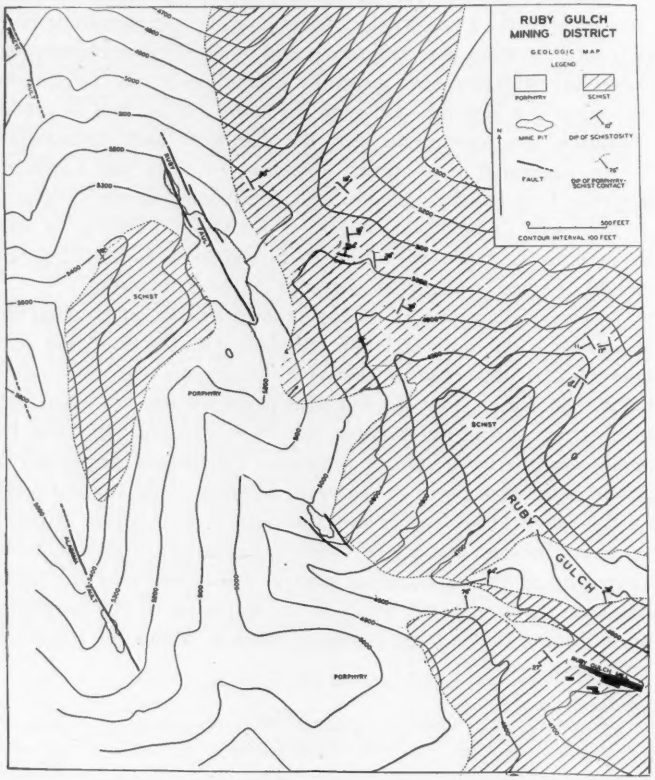

FIG. 2. Geologic map of Ruby Gulch Mining District.

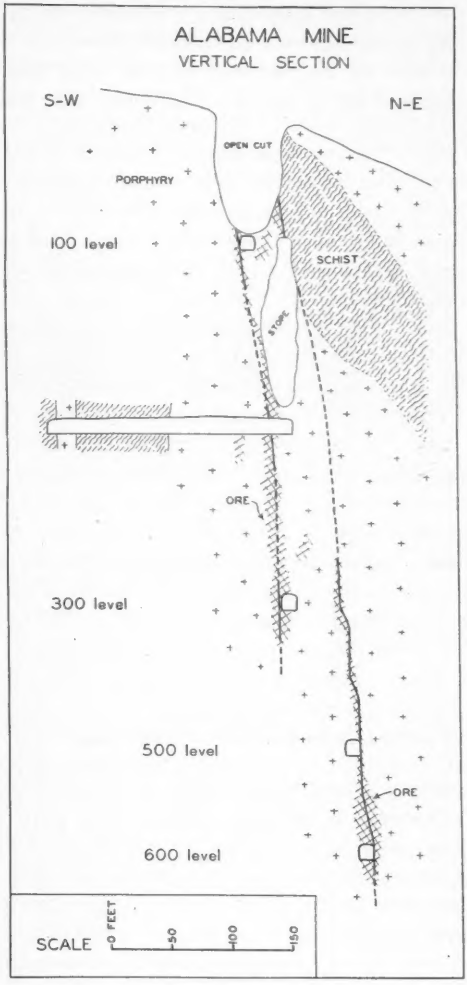

FIG. 3. Vertical section, Alabama Mine.

In the vicinity of the Ruby Gulch ore bodies, contacts between porphyry and metamorphics are extremely sinuous on the surface (Fig. 2) in spite of the fact that, for the most part, they are steeply inclined (Figs. 3 and 4). In most cases noted under-

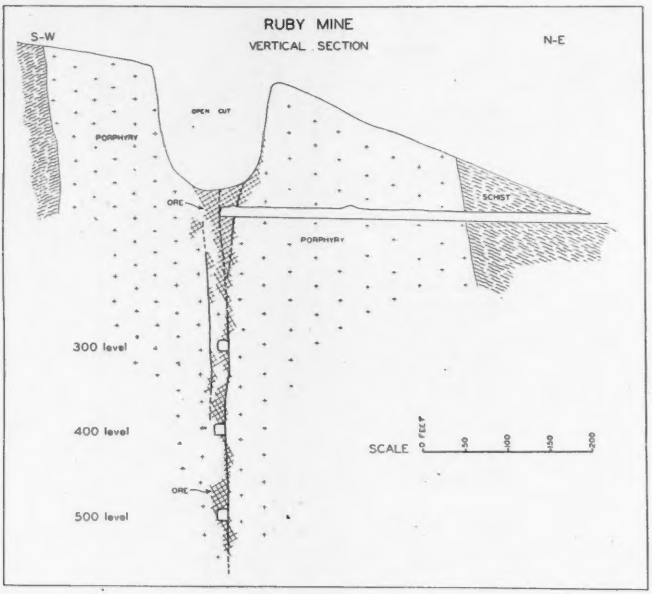

FIG. 4. Vertical section, Ruby Mine.

ground, porphyry-schist contacts have a steeper dip than the planes of schistosity in adjacent schists. The porphyry mass thus appears to be of very irregular form without a definite base, and as said before, cannot properly be termed a simple laccolith. It is suggested that large isolated masses of limestone and schist in the vicinity of Ruby Gulch, which are completely surrounded by porphyry, may be roof pendants extending downward into the intrusive (Fig. 1).

Petrography.—The igneous rocks of the Little Rocky Mountains are mostly of intermediate chemical composition and belong

to the alkali granite syenite series,[9] being, on the whole, low in lime, iron, and magnesia, as indicated by the uncommoness of minerals containing these elements, and by the alkaline nature of the feldspars. There has been some differentiation or variation in character from true granite porphyries to syenite porphyry, and although the alkaline intrusive mass is generally high in silica, a local differentiation has produced a phonolite with the composition of tinguaite. This rock was first mentioned by Weed[10] and occurs on the border of the main porphyry mass at its contact with the basal Cambrian quartzite.

Basic Dike Rock.—About one mile outside of the main porphyry intrusive mass in the vicinity of Ruby Gulch there is a narrow dike, which may be a lamprophyric facies of the main body of the porphyry. Megascopically it has a fine-grained, bluish-gray groundmass and reveals an abundance of small but recognizable olivine and biotite phenocrysts. Under the microscope it is seen to be composed of abundant nepheline, biotite, and olivine phenocrysts. Considerable fine-grained magnetite derived possibly in part from the alteration of olivine is also present. Feldspars, pyroxenes, and amphiboles are absent. The abundance of nepheline is characteristic of rocks formed from magmas rich in soda and low in silica. Thus, the composition of the rock is unusual, inasmuch as the main porphyry intrusive is fairly high in silica and lacks ferromagnesian minerals. Because of the alkalic character of the feldspathoid (nepheline) the rock must have been derived from a magma characterized by alkalic feldspars. Nepheline has crystallized in place of the feldspars. The apparent relation of this rock to the phonolite differentiate first noted by Weed[11] substantiates the view that it is related to the basic alkaline clan of igneous rocks and is a lamprophyric differentiate of the magma that formed the main intrusive of the mountains.

Syenite Porphyry.—The most common variety of the porphyry, and the one that is mineralized in the Ruby Gulch District, is a

[9] Weed and Pirsson.: *Op. cit.*, p. 425.

[10] Weed, W. H.: Ore deposits of the Little Rocky Mountains, Montana. Eng. and Min. Jour., 61: 423–424, 1896.

[11] *Op. cit.*

light to dark gray rock generally distinguished by abundant orthoclase phenocrysts. These phenocrysts in several localities attain lengths of 25 mm. However, in the vicinity of Ruby Gulch maximum dimensions of feldspar phenocrysts are mostly less than 10 mm. Thin sections show a very fine, even-grained groundmass of feldspar, with phenocrysts of orthoclase and plagioclase, the former being the more common. Acid oligoclase is the type of plagioclase most commonly present. Quartz phenocrysts in places occur sparingly. Zircon and apatite are rare accessory minerals.

With the exception of several well defined dikes there is a distinct intergradation of porphyry types.

STRUCTURAL FEATURES.

A group of high-angle faults radiate from the center of the mountains. In the Ruby Gulch area the trend of these faults is N. 25° W. They are confined almost entirely to the porphyry and their walls are prominently slickensided and grooved. Locally, crushing has been intense in narrow zones (usually ten to twenty feet maximum) and there are thin streaks of gouge along these faults. They have served as channels for ascending solutions from which were deposited the ore minerals. At places, ore and gangue have been crushed and comminuted, indicating that there has been some movement along the faults subsequent to the earlier phases of mineralization. The writer suggests that these faults, along which ores have been deposited, were formed by relaxation in the upper part of the intrusive after it had consolidated. Gravity faults are common in domed areas and Spurr [12] noted that later movements along faults at Tonopah, Nevada, had resulted from subsidence. Further, the radial pattern of the faults suggests relaxation rather than upthrusting. In the latter case, shearing stresses probably would be set up, and would give rise to horizontal displacements, no evidence of which was found along the faults. Relaxation, too, would probably enable the ore solutions to rise with more facility than under

[12] Spurr, J. E.: Geology of the Tonopah mining district, Nevada. U. S. Geol. Surv. Prof. Paper 42: 47, 1905.

other conditions of stress. Displacement along the faults is probably not great; 100 to 200 feet may be a maximum. Crushing and comminution is locally intense but is limited to narrow zones, and coarse breccia is scarce.

ORE DEPOSITS.

General.—The most important ores of Ruby Gulch are low grade and are concentrated along high-angle faults in porphyry. At places, nearby schists have been mineralized. The vein matter occurs chiefly in close association with the crushed zones, either filling cavities or replacing rock fragments. In addition, it may occur as disseminated replacements in the porphyry wall rock outside of these zones. The ores have been mined mainly in the oxidized zone, but several sulphide lodes have been located. A characteristic feature of the deposits is the small number of minerals contained in them. With few exceptions, quartz, pyrite, and fluorite are the only megascopically visible minerals of the ore zones.

Because of the general low-grade character of the ores and the complete absence of well-defined boundaries to the ore bodies it is difficult to determine the dimensions of individual ore-shoots. The principal body in the Ruby Gulch area has been productive for over 1200 feet in length, and over 500 feet in vertical extent. In places, the zone of workable ore has a width of about fifty feet.

Contact-metamorphic deposits, a few of which occur in limestone near intruding porphyry have been proven to be, on the whole, economically unimportant in the Ruby Gulch area.

The Sulphide Zone.—In the sulphide zone quartz and pyrite are the two commonest minerals. The wall rocks of the faults have been intensely silicified in narrow zones by the introduction of early quartz accompanied by minor amounts of pyrite, the latter occurring mainly as small grains disseminated through the silicified porphyry, and less commonly as thin veneers on fault surfaces. Extremely fine-grained gold occurs with the quartz and may be mechanically mixed with pyrite. Veinlets of quartz

and pyrite occur within the silicified porphyry. Gold also occurs with sylvanite, deposited within cavities in quartz veinlets (Figs. 5 and 6).

Fluorite, although abundant locally, occurs sporadically and is always close to the major faults; its zone of occurrence is rarely

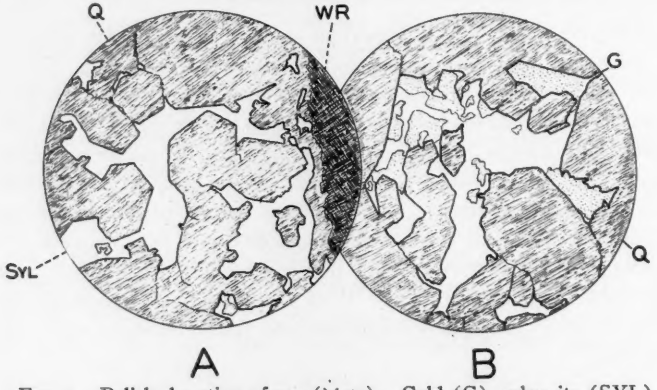

FIG. 5. Polished section of ore (× 50). Gold (G), sylvanite (SYL), quartz (Q), porphyry wall rock (WR).

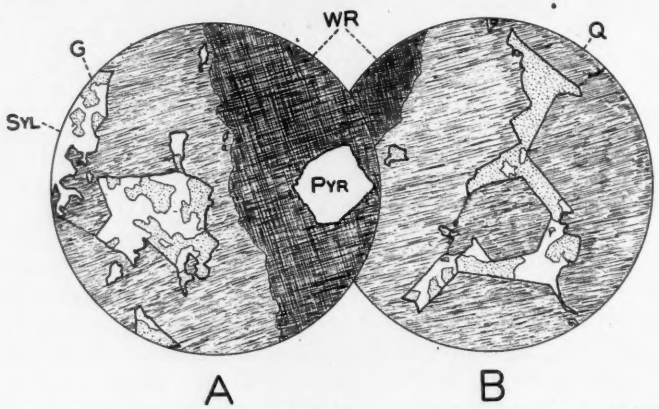

FIG. 6. Polished sections of gold-sylvanite-quartz veins, × 50. Gold (G), sylvanite (SYL), quartz (Q), porphyry wall rock (WR), pyrite (PYR).

more than two or three feet wide. Ordinarily it is fine-grained and occurs as a cementing material of crushed porphyry fragments. It has been found on all levels but is most abundant above the 300-level.

Sericite is the chief alteration product of feldspar and is abundant in the walls of most of the veins, where it is directly related to channels of mineralization. Epidote is somewhat rare although its persistent occurrence as minute crystals in altered plagioclase is characteristic. Calcite occurs sparingly as small replacement veinlets in the porphyry.

The Oxidized Zone.—Oxidation reaches depths of more than 500 feet below the present surface. In localities where crushing is extensive the porphyry has been altered to a soft brown earthy material. This soft zone varies from a few inches to twenty feet or more in width and grades into solid porphyry. A mixture of hydrous iron oxides, and quartz is often noted, especially close to the faults. Limonite generally occurs as pseudomorphs after pyrite crystals. Manganese oxides are present in the highest levels along one of the faults.

Melanterite is common in old mine workings, particularly near the lower limit of the oxidized zone. It forms by evaporation of sulphate waters that descend through the crushed zones along the faults, and generally occurs as conspicuous light-green to brownish crusts and stalactitic growths.

Kaolinite is not common, but is found as a weathering product of feldspars.

Mineral Relations.—The first definite phase of mineralization consisted of deposition of quartz and minor amounts of pyrite and gold, accompanied by sericitization. Quartz deposition took the form of silicification of the porphyry wall rock and the mineral is extremely fine grained. Adjacent to fault surfaces this quartz appears as narrow, more or less distinct bands. Although there are no large veins of quartz in the ore zones, its occurrence in the silicified porphyry and its presence in small veinlets and cavity fillings in the crushed zones make it the most common mineral of the deposits. Pyrite is the only sulphide of the deposits

and, next to quartz, is the most common mineral in the ore zones. However, nowhere is it present in large masses, although it can be found disseminated and in veinlets throughout all unoxidized parts of the ore bodies.

This first epoch of mineralization was followed by a period during which secondary movement occurred along the faults. It resulted in crushing of the quartz and slickensiding of the pyrite along fault surfaces. During the next stage of mineralization, quartz of slightly coarser grain, and a small amount of pyrite were deposited. Additional sericitization probably took place at this time. Close to the faults this second generation of quartz either completely or partially cements crushed fragments of the previously silicified porphyry.

After this phase of mineralization fluorite was introduced. In a narrow zone along the faults it was deposited in remaining cavities which had not been completely filled by the earlier quartz deposition.

A major period of gold and sylvanite deposition followed the late quartz and was probably contemporaneous with, but possibly slightly later than the fluorite. Mineragraphic examination shows that the late gold and sylvanite, in all cases where seen, were deposited in remaining hollows and were definitely later than the second generation of quartz.

Summary of Paragenesis.—The general order of deposition of the minerals appears to be as follows: (1) quartz, pyrite, sericite, gold; (2) quartz, pyrite, sericite, calcite?; (3) fluorite; (4) gold and sylvanite.

GENETIC CLASSIFICATION.

Several features of the Ruby Gulch ores support the supposition that they were deposited in the epithermal zone of ore deposition by ascending thermal solutions emanating from a cooling igneous mass into its consolidated border which itself represents a shallow zone of emplacement.

Vugs, mostly small, with drusy masses of quartz, as well as some gold and sylvanite, are abundant along all the faults and

throughout the crushed zones. The fineness of the grain of all minerals, ore and gangue, is apparently a direct consequence of rapid loss of heat from the solutions.

ACKNOWLEDGMENTS.

The writer is much indebted to the management of the Ruby Gulch Mining Company for permission to carry on the field work and publish the results, and to Dr. J. D. Forrester of the Anaconda Copper Mining Corporation for suggesting the work. Thanks are due to Professor H. Ries, under whose direction the work was carried on, and Professor C. M. Nevin for suggestions during the laboratory investigation and the preparation of the manuscript.

CORNELL UNIVERSITY,
ITHACA, NEW YORK,
December 12, 1938.

THE PYROSYNTHESIS, MICROSCOPE STUDY AND IRIDESCENT FILMING OF SULPHIDE COMPOUNDS OF COPPER WITH ARSENIC, ANTIMONY AND BISMUTH.

A. M. GAUDIN AND GÜNTHER DICKE.

PART II.

COPPER-BISMUTH-SULPHUR SYSTEM.

No data are available in the literature concerning this system. Of the many natural minerals said to occur in this system the following, only, are generally accepted by mineralogists: emplectite $Cu_2S \cdot Bi_2S_3$; klaprothlite $3Cu_2S \cdot 2Bi_2S_3$; wittichenite $3Cu_2S \cdot Bi_2S_3$.

According to Dana and Ford,[6] cuprobismutite is probably identical with emplectite. Schneiderhöhn and Ramdohr, however, describe it as a separate mineral species having the formula $3Cu_2S \cdot 4Bi_2S_3$. The existence of a pure bismuth-tetrahedrite is doubtful, most authors referring only to a " bismuth-rich variety of tetrahedrite."

In Tables VIII and IX characteristic specimens are listed, chosen from the odd five hundred mechanically sound specimens which were prepared. In these tables the phases and structures observed are listed. It can be seen that the presence or absence of excess sulphur is of substantial influence upon the occurrence of phases and upon the structural relationship. Because of the complexity of the system the discussion will be divided into two parts, one dealing with the conditions in specimens rich in sulphur, the other with those poor in sulphur.

All specimens were prepared by melting together metallic copper, bismuth and flowers of sulphur. The proportion of copper to bismuth as given in Tables VIII and IX is probably close to the actual composition of the specimens because of the non-volatility

of the metals and of their sulphides. The weights as mixed into the crucible and the weights of the samples after fusion were generally in good accord. A certain allowance for loss of sulphur has of course to be made.

For the identification of phases, the method of selective iridescent filming was applied and was of invaluable help. The similarity of the phases in their natural color and optical properties made impossible a distinction based upon the usual methods of determination. Good filming results were obtained with the HCl–CrO_3 and H_2SO_4–CrO_3 solutions. A 1 : 1 mixture of these

TABLE VIII.

CHARACTERISTIC SPECIMENS PREPARED IN THE COPPER-BISMUTH-SULPHUR SYSTEM IN THE PRESENCE OF EXCESS SULPHUR.

Atomic Per Cent		Phases	Structure	Heat Treatment*	Photomicrograph
Cu	Bi				
21.5	78.5	Bismuthinite Phase A Sulphur	In a groundmass of phase A large crystals of bismuthinite which are partly indented by phase A	*a*	26
44.1	55.9	Phase A Covellite Phase B Sulphur	Primary phase A in eutectic of phase A and covellite. Only a small amount of phase A in the core of the specimen is changed over to phase B	*b*	27
44.1	55.9	Phase A Covellite Phase B Sulphur	The transformation of phase A to phase B has gone very far. Phase B in long needles cutting the covellite	*c*	28
57.5	42.5	Phase A Covellite Phase B Sulphur	Eutectic of phase A and covellite. Only very few needles of phase B as decomposition product from phase A	*b*	—
57.5	42.5	Phase A Covellite Phase B Sulphur	The greatest part of phase A is transformed into phase B. Almost all of the covellite is dissolved	*d*	29
68.3	31.7	Chalcocite Covellite Phase C Phase A Phase B Sulphur	Chalcocite in dendrites, covellite in long plates. Phase C is transformed partly into phase A and the latter into B. Precipitation of covellite from the transformation of phase C into phase A	*a*	—

TABLE VIII—*Continued.*

Atomic Per Cent		Phases	Structure	Heat Treatment*	Photomicrograph
Cu	Bi				
76.3	23.7	Chalcocite Covellite Phase C Phase A Sulphur	Fossil chalcocite, covellite in long plates. Phase C is in the state of transformation to phase A with precipitation of silky covellite	*b*	—
82.8	17.2	Chalcocite Covellite Phase C Sulphur	Dendrites of chalcocite and covellite plates in a groundmass of phase C. The transformation has not yet started	*e*	30
88.2	11.8	Chalcocite Covellite Phase A Phase B Phase C Sulphur	Fossil chalcocite and big plates of covellite. Phase C is transformed partly to phase A and the latter is in the state of decomposition to phase B	*a*	33
92.9	7.1	Chalcocite Covellite Phase C Phase B Sulphur	Primary covellite in plates, chalcocite in dendrites. Phase C is transformed immediately into phase B	*a*	35

* *a*—Heated to 680° C. Cooled at normal furnace rate to 350° C., then quenched.
b—Heated to 600° C. Cooled at normal furnace rate to 590° C., then quenched.
c—Heated to 620° C. Cooled 13° each hour to 300° C., then quenched.
d—Heated to 725° C., cooled slowly.
e—Heated to 750° C., quenched.

solutions was of help in the differentiation between two special phases.

Specimens Prepared in the Presence of Excess Sulphur.

Discussion of Phases.

In addition to the sulphides of the metals, three sulpho-salts (A, B, and C) have been obtained.

Bismuthinite shows a typical white color, good cleavage and a difference in hardness in different orientations. It is strongly anisotropic and displays some pleochroism. It films in the HCl–CrO_3 solution with considerable variation in different crystal orientations. The filming rate of bismuthinite is uniform in all

TABLE IX.

SELECTIVE DESCRIPTIVE LIST OF SPECIMENS PREPARED IN THE COPPER-BISMUTH-SULPHUR SYSTEM IN THE ABSENCE OF EXCESS SULPHUR.

Atomic Per Cent		Phases	Structure	Heat Treatment*	Photomicrograph
Cu	Bi				
44.1	55.9	Bismuthinite Phase M Metal	Primary bismuthinite in rounded crystals in a groundmass of phase M and metal	*a*	—
57.5	42.5	Phase M Bismuthinite Metal	Phase M as primary phase with typical equidimensional grains. Bismuthinite and metal, the latter being segregated at the bottom of the specimen	*b*	—
68.3	31.7	Phase M Bismuthinite Metal	Very uniform groundmass of phase M with small amount of bismuthinite and metal	*b*	—
76.3	23.7	Phase M Chalcocite	Primary phase M with rounded edges and partly indented in a matrix of chalcocite	*c*	—
88.2	11.8	Chalcocite Phase M	Dendrites of phase M with ex-solution —chalcocite in an eutectic of phase M and chalcocite	*a*	—

* *a*—Heated to 650° C. Cooled at normal furnace rate to 200° C., then quenched.
b—Heated to 525° C. Cooled at normal furnace rate to 200° C., then quenched.
c—Heated to 550° C. Cooled at normal furnace rate to 200° C., then quenched.

specimens high in sulphur, which indicates a lack of substantial solid-solution effects. Even as low a copper content as 0.5 per cent brings about the crystallization of some phase A. This sets an upper limit to the possible copper content of bismuthinite.

Phase A is grayish-white in color, strongly anisotropic, and does not show cleavage. Its reflectivity is slightly less than that of bismuthinite. In the H_2SO_4–CrO_3 solution it films with great color variation in different crystal orientations. In the HCl–CrO_3 solution it films very slowly (tan after ten minutes) again with considerable variation in different orientations. Phase A also films differently in different specimens but uniformly within one specimen. In specimens near the bismuth-end of the system, phase A films more slowly than in specimens with higher copper content. This is interpreted to mean that phase A is

capable of undergoing solid solution to an appreciable extent. The combined filming solution gives good results on phase A (orange-purple after 3 minutes). It is thus easily differentiated from phase B which does not film in this bath. The film on phase A in the H_2SO_4–CrO_3 solution is characterized by color-fading if viewed under oil, a phenomenon which indicates that the index of refraction of the film substance is relatively close to that of the oil ($n = 1.51$).[3]

Phase B has a pinkish-gray color, is strongly anisotropic and is characterized by needle-shaped crystals. It films in the H_2SO_4–CrO_3 solution slower than phase A. It does not film in the HCl–CrO_3 solution, nor in the combined solution. Phase B shows but little variation in filming rate from specimen to specimen, indicating very limited solid-solution. In accordance with its extreme anisotropy considerable variation in filming rate is noticeable with variation in crystal orientation.

Phase C has a grayish-white color, and is slightly anisotropic. It films in the H_2SO_4–CrO_3 solution at a rate similar to that of phase A. In different specimens, phase C shows considerable variation in filming rate; this may indicate a tendency of phase C to form solid solution. A differentiation between phases C and A if filmed in H_2SO_4–CrO_3 solution is possible if the specimen is viewed under oil. The film on phase C retains its intense interference colors while the film on phase A fades.

The appearance and physical properties of *covellite* do not differ from those described already.

Chalcocite differs from the chalcocite described in connection with other systems in that it seems to dissolve large quantities of bismuth. This becomes obvious wherever chalcocite has been changed to covellite by the ex-solution precipitation of phase C as sharp needles sticking into the covellitized dendrites of chalcocite (Fig. 34).

Table X presents a record of the mineral composition in specimens containing excess sulphur. This record is approximated to the nearest whole per cent. Table X shows that as the copper content increases the sulpho-salts appear and disappear in the

order A, B, C. It is also seen that copper sulphides appear at a lower copper content than phase C.

From the data presented in this table and from others that are not included, the atomic ratio of copper to bismuth in phases A, B, and C is found to be approximately 1:2; 3:2; 6:2. In making the necessary calculations assumptions have had to be made for the specific gravities of phases A, B, C. The minimum specific gravity for a sulpho-salt can be calculated from the specific gravity of the end-sulphides by LeChatelier's law. Accordingly the specific gravities of A, B, and C, have been taken as 6.1; 5.7; and 6.1 respectively.

TABLE X.

QUANTITATIVE MINERAL COMPOSITION OF COPPER-BISMUTH-SULPHUR PREPARATIONS

Metal Content, Atomic Per Cent		Mineral Content, Volume Per Cent				
Copper	Bismuth	Bismuthinite	A	B	C	Chalcocite and covellite
11.8	88.2	66	34	—	—	—
21.9	78.1	30	70	—	—	—
26.3	73.7	17	83	—	—	—
30.6	69.4	10	70	18	—	2
38.0	62.0	—	57	39	—	4
44.6	55.4	—	50	46	—	4
58.1	41.9	—	24	72	—	4
63.5	36.5	—	13	79	—	8
68.3	31.7	—	3	84	—	13
72.5	27.5	—	1	83	—	16
76.5	23.5	—	—	52	31	17
82.9	17.1	—	—	45	35	18
88.3	11.7	—	—	7	58	35
92.8	7.2	—	—	—	35	65
96.7	3.3	—	—	—	7	93

If the atomic ratio of copper to bismuth in phase A is 1:2 the formula is either $Cu_2S \cdot 2Bi_2S_3$ or $CuS \cdot Bi_2S_3$. In view of the fact that phase A does not form in the absence of excess sulphur (as explained below), and in view of the greater simplicity of the second formula, that formula is preferred. It is possible that phase A is identical with cuprobismutite, although the formula given for the latter is more complex, namely, $3Cu_2S \cdot 4Bi_2S_3$. Such a complex formula is unlikely and possibly based on a

mechanical mixture of cuprobismutite with other copper-bismuth sulphides.

If the atomic ratio of copper to bismuth in phase B is 3:2 the formula is either $3Cu_2S \cdot 2Bi_2S_3$ or $3CuS \cdot Bi_2S_3$. In view of the fact that phase B requires excess sulphur for its formation it is practically certain that cupric copper rather than cuprous copper is involved. The second formula is therefore adopted. It is likely that this phase is klaprothite.

If the atomic ratio of copper to bismuth in phase C is 6:2 the formula is either $3Cu_2S \cdot Bi_2S_3$ or $6CuS \cdot Bi_2S_3$. Evidence presented below indicates that phase C occurs either in the presence or absence of excess sulphur, and that in the presence of excess sulphur it reacts with the latter on cooling to form covellite and phase B. Accordingly, it is preferable to regard phase C as containing cuprous copper, perhaps with a generous tendency to form solid solutions containing excess sulphur. The first formula is therefore indicated, namely $3Cu_2S \cdot Bi_2S_3$. This would make phase C correspond to wittichenite, which it otherwise resembles. It is to be noted that although phase C is homologous with tetrahedrite and tennantite, it is obviously not isomorphous with them.

Discussion of Structures.

The structural relationships are complex, and unless special attention is paid to the heat-treatment followed they may remain completely beyond understanding. In order to present the results in the simplest way, reference should be made to Fig. 23. This figure is not an equilibrium diagram since the pressure of sulphur vapor was not kept constant, but was allowed to adjust itself to the temperature. Temperatures were recorded to $\pm 5°$ C. with a chromel-alumel thermocouple immersed together with the bombs in a bath of melted lead-tin alloy. Quenching was obtained by grasping the bomb in tongs and placing it under a substantial jet of water. Cooling of the bombs required perhaps 15 to 30 seconds; properly speaking therefore it is not a quench, but a cooling process many times faster than cooling in air or in the furnace. Compared to the slow furnace cooling otherwise used,

the bomb "quenching" is faster by perhaps a thousand-fold. Substantiating the opinion that the quench was defective is the common observation that quenched buttons show distinct rimming structure, the rim appearing to have cooled faster.

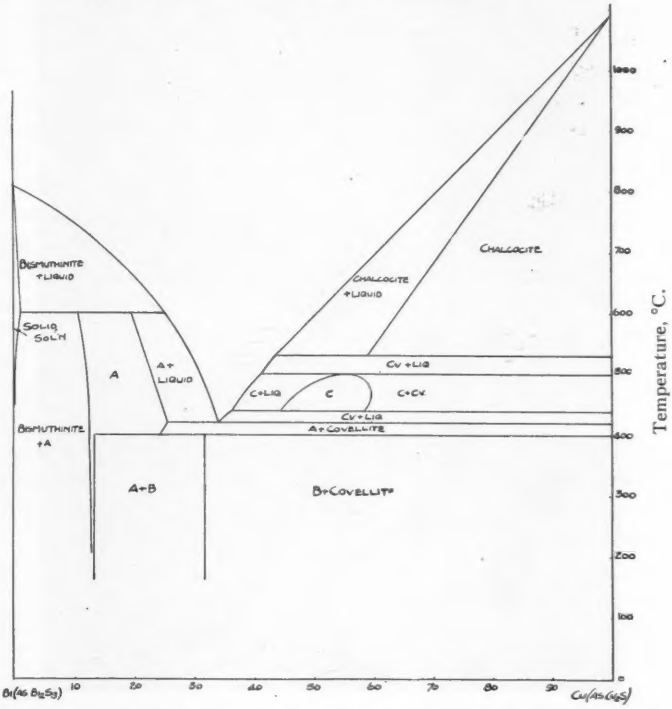

FIG. 23. Sketched diagram of the Cu–Bi–S system in the presence of excess S.

Fig. 23 shows that the primary phases include bismuthinite, A, C, covellite and chalcocite. Phase B is always formed in the solid state. Neither chalcocite nor phase C are stable at room temperature, their occurrence being merely evidence of incompleted reaction with sulphur. If the copper content is relatively

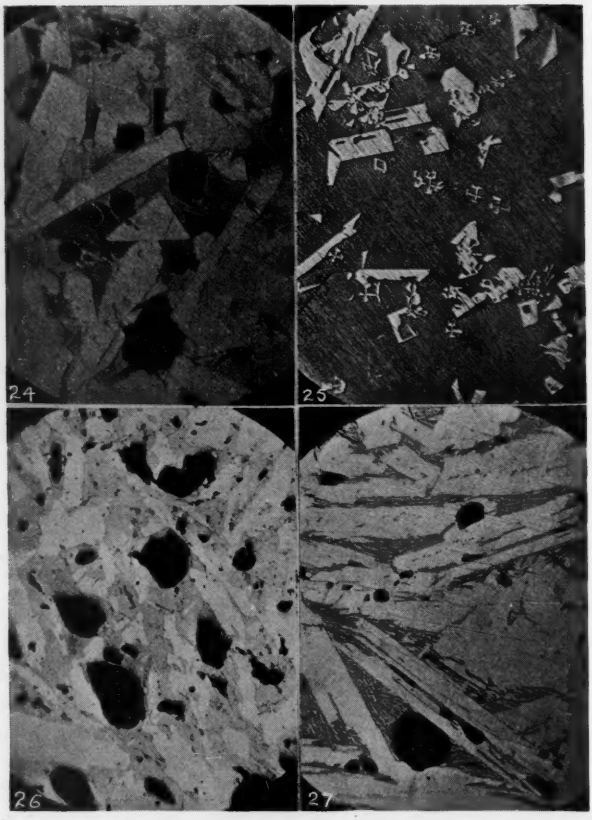

FIG. 24. Dendrites of primary enargite (white) and famatinite (dark gray) in a groundmass of As–S glass. The black spaces are pits. Filming time 40 seconds HCl–CrO_3 solution. Colors: enargite, white; famatinite, brown; tennantite, pale blue; As–S glass, gray. × 60.

FIG. 25. Typical "iron-cross"-shaped crystals of tennantite-tetrahedrite with blockey crystals of enargite in As–S glass. Unfilmed. × 60. Oil.

FIG. 26. Bismuthinite in a groundmass of phase A. The black areas are holes. Filming time 3 minutes H_2SO_4–CrO_3 solution. Colors: bismuthinite, white; phase A, orange-brown (gray). × 60, oil.

high two ranges of "mushiness" appear, one in the range of 500–530° C., the other in the range of 420–440° C. These ranges of mushiness correspond to the reactions with sulphur of chalcocite, and phase C, respectively.

Bismuthinite occurs as a primary phase in idiomorphic, elongated crystals together with phase A. It is often strongly indented and partly resorbed (Fig. 26). This constitutes positive evidence of reaction of bismuthinite with residual melt to form phase A; in other words that phase A has an incongruent melting point.

Phase A (cuprobismutite) occurs in three associations: (1) as a secondary phase, surrounding bismuthinite; (2) in big, compact primary crystals; and (3) in eutectic with covellite (Fig. 27). Its tendency to undergo solid solution seems to be appreciable as can be concluded from its changing filming rate and the variation in calculated composition. At about 400° C. it reacts with covellite in the solid state to yield *phase B*.

Phase B (klaprothite) often grows into primary crystals of A (Fig. 29), and when that happens there often appears a change in the filming rate of the residual phase A in the rims as compared with the residual phase A in the cores. This common phenomenon justifies the view that appreciable solid solution of excess copper in phase A is possible only above the decomposition temperature of phase B. Phase B also occurs as long needles cutting across plates of primary covellite (Fig. 28), across the eutectic of A with covellite, and across residual areas of phase C (Fig. 33, 35) which were cooled too rapidly to permit of complete reaction with sulphur.

Phase C (wittichenite) occurs in compact crystals together with covellite, the latter being either primary or decomposed from chalcocite (Fig. 30). The tendency of phase C to form solid solution is considerable. On cooling in sulphur vapor phase C melts by reaction with sulphur, decomposes into phase A (Fig. 33), or decomposes immediately into phase B (Fig. 35).

FIG. 27. Specimen quenched. Primary phase A in eutectic of covellite and phase A. There is no evidence of transformation of phase A into phase B. Unfilmed. × 60.

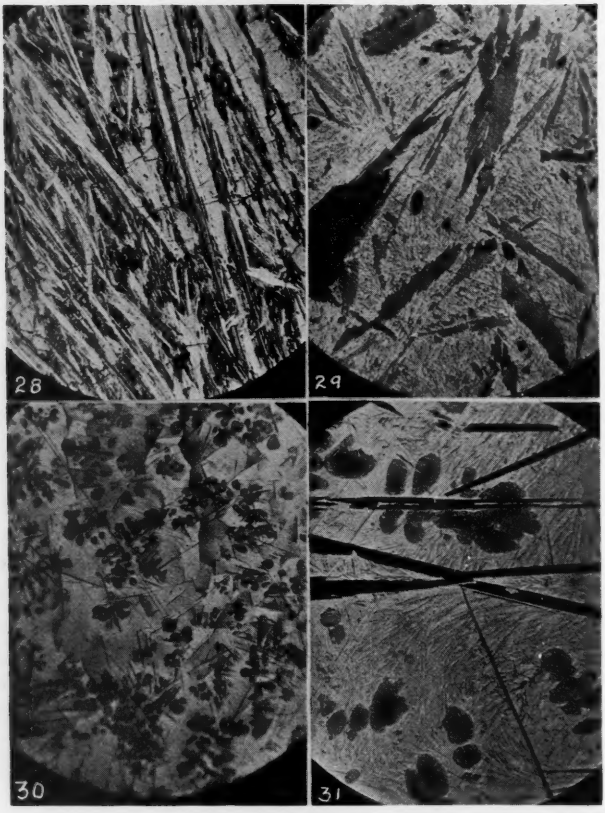

FIG. 28. Specimen of the same composition as Fig. 27, cooled slowly. Much of phase A is transformed into needles of phase B which cut the covellite. Filming time 1 minute H_2SO_4–CrO_3 solution. Colors: phase A, orange (grayish white); phase B, pale tan (white); covellite, blue (gray). × 60.

FIG. 29. Specimen cooled slowly, remainders of phase A in a groundmass of phase B and a small amount of covellite. Filming time 3 minutes combined solution. Colors: phase A, orange-brown (medium gray); phase B, white; covellite, blue (medium gray). The dark gray areas are pits. × 60.

The temperatures at which C reacts with sulphur to give a melt, at which the eutectic of A and covellite crystallizes, and at which A reacts with covellite to give B are close to each other so that a record of the sequence is not observed in all cases. This appears reasonable when it is considered that the molecules involved are relatively complex.

In specimens containing less than 60 per cent Cu_2S (rated on the total sulphide content) the transformation of C to A and then B is currently observed, but on specimens with a higher copper content phase B seems to form directly from C.

Covellite occurs in four forms: 1, as decomposition product from chalcocite (Figs. 32, 34); 2, as a primary phase (Fig. 30); 3, as eutectic with phase A (Fig. 27); 4, as a precipitate formed during the transformation from phase C to phase A (Fig. 31).

Chalcocite occurs as primary phase in dendritic form and is retained in slowly cooled specimens only as fossil (Fig. 34).

Specimens Prepared in the Absence of Excess Sulphur.

A study of the system in the absence of excess sulphur was made by preparing sets of specimens with changing sulphur content. The results are simple. Only three phases are observed: bismuthinite, chalcocite, and a compound, phase M, that forms eutectics with each of the other phases.

Bismuthinite grades somewhat in its natural color from white in specimens at the Bi_2S_3—end of the system to pinkish-gray in specimens higher in copper. Its cleavage is not as perfect as in

FIG. 30. Specimen quenched. Dendrites of chalcocite partly changed over to covellite and covellite plates in a groundmass of phase C that shows grading in color (solid-solution effect?). Decomposition of C has not started. Filming time 1 minute H_2SO_4–CrO_3 solution. Colors: phase C, grading blue; chalcocite, gray-blue; covellite, blue. × 140, oil.

FIG. 31. Specimen of the same composition as No. 30 cooled slowly. Three kinds of covellite: primary, in long plates; as decomposition product from chalcocite in rounded aggregates; and precipitated during the decomposition of phase C as silky platelets. The transformation of C to B is complete. Unfilmed. × 140, oil.

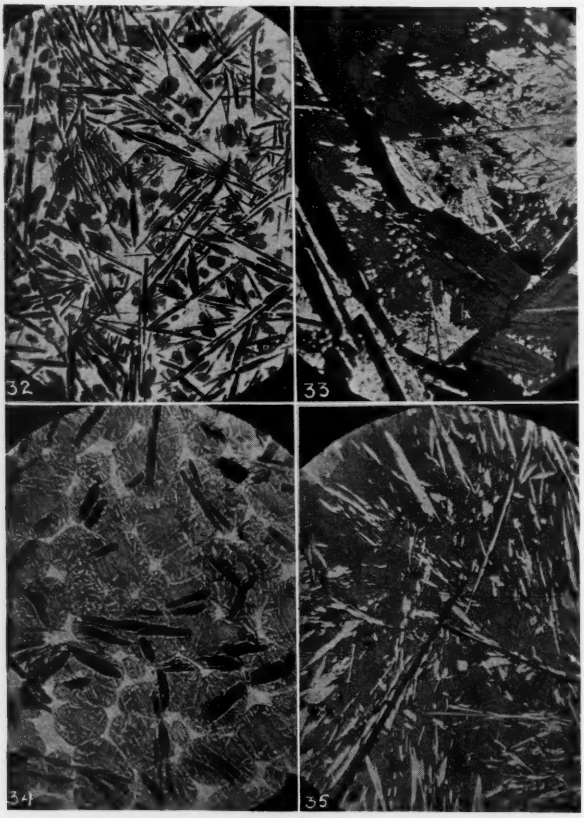

FIG. 32. Specimen quenched. Dendrites of fossil chalcocite and plates of covellite (dark gray) in a groundmass of phase C. The decomposition of phase C has not started. Unfilmed. × 140, oil.

FIG. 33. Specimen of same composition as Fig. 32, cooled slowly. Large plates of primary covellite surrounded by phase C. Phase C is partly transformed into phase A with precipitation of fibrous covellite (center, pale gray) and into phase B as needles (white), which grow into phase A. This field shows all the transformations that take place. Filming time 1 minute H_2SO_4–CrO_3 solution. Colors: phase C, light blue

samples prepared in the presence of excess sulphur. Its filming rate is different: this bismuthinite does not film in the HCl–CrO_3 solution and films slowly in H_2SO_4–CrO_3 solution. This suggests that this form of bismuthinite may contain considerable copper in solid solution.

Phase M has a grayish-white color, is strongly anisotropic and occurs in compact crystals. It is characterized by equi-dimensional grains and by its filming behavior (brownish-yellow after 1 minute H_2SO_4–CrO_3 solution). One specimen containing 40 per cent Cu_2S consists almost entirely of this phase. That specimen contains in addition small quantities of bismuthinite and of bismuth. Phase M must therefore contain more than 40 per cent but less than 50 per cent Cu_2S because the 50%–Cu_2S specimen contains an appreciable amount of chalcocite. An exact calculation of the composition of phase M is impossible, because the composition of the metal and bismuthinite is unknown. But it seems to approximate the composition $3Cu_2S \cdot Bi_2S_3$ (Cu_2S = 48.2 per cent as a mean). Phase M may well correspond to wittichenite and yet it is rather distinct from phase C in its behavior toward polarized light as well as toward filming solutions. Thus wittichenite would have to be regarded as dimorphous, the modification in the absence of excess sulphur being phase M.

Gradations from phase M to phase C were sought in speci-

(gray); phase A, orange (pale gray); phase B, tan (white); covellite, blue (dark gray). × 140, oil.

FIG. 34. Specimen quenched. Dendritic fossil chalcocite changed over on the rims into covellite and phase C; primary covellite in plates (dark gray) and groundmass of phase C (white). Note the difference in natural color of primary covellite and the covellite as decomposed from chalcocite. Unfilmed. × 140, oil.

FIG. 35. Specimen cooled slowly. Plates of primary covellite (dark gray) in phase C (gray). Phase C has begun direct transformation into needles of phase B (white) without noticeable passage through the stage of phase A. Specimen has the same composition as that shown in Fig. 34. Filming time 1 minute H_2SO_4–CrO_3 solution. Colors: phase C, blue; phase B, tan; covellite, blue. × 140, oil.

TABLE XI.

IDENTIFICATION GUIDE.*

Interference Colors on Synthetic Minerals as a Function of the Time of Exposure to Standard HCl-CrO_3 Solution Observed with Low-Power Objective in Air.
Temperature of Bath 18–20° C.

Phases	Duration of Exposure to Standard HCl-CrO_3 Solution							Remarks
	10 Seconds	30 Seconds	45 Seconds	1 Minute	2 Minutes	3 Minutes	5 Minutes	
Arsenic-sulphide glass				Pale brown-gray	Brown-gray	Violet-gray	Blue-gray	
Bismuthinite				Pale tan	Tan-yellow	Yellow-orange	Orange to violet	Colors markedly depend on crystal orientation
Cupriferous Bismuthinite	Unchanged							
Chalcostibite		Pale tan	Yellow-orange	Blue	To high-order colors			
Enargite	Unchanged							
Famatinite "A"		Tan	Orange I	Violet	Pale blue			Occurs in association with chalcostibite
Famatinite "B"	Unchanged							In specimens high in sulphur
Famatinite "C"	Unchanged							Occurring in association with chalcocite and covellite
Natural orpiment				Light tan	Tan-brown	Brown	Brown-violet	
Phase "A" cuprobismutite							Pale tan	
Phase "B" klaprothite	Unchanged							
Phase "C" wittichenite							Pale tan	

* As to the use of the Identification Guide see text, p. 57.

TABLE XI—*Continued.*

Phases	Duration of Exposure to Standard HCl–CrO_2 Solution							Remarks
	10 Seconds	30 Seconds	45 Seconds	1 Minute	2 Minutes	3 Minutes	5 Minutes	
Phase "M" variety of wittichenite	Unchanged							
Natural realgar	Light tan	Dark tan	Brown-violet	Violet	Blue I	Deep blue	Deep blue	
Stibnite	Tan-yellow	Blue-pale blue	Yellow II	Green II	To high-order colors			
Tennantite I						Orange I		Films slower than tennantite II
II			Pale tan	Yellow-orange	Violet-blue	Blue I	To high-order colors	
Tetrahedrite A		Pale violet	Blue					
B		Faded violet	Pale violet	Gray-blue	Pale blue	To high-order colors		
C							Pale tan	

mens having intermediate sulphur content. The results are not altogether convincing that there is a gradation and that is why it is tentatively preferred to regard M and C as allotropic modifications of wittichenite.

Chalcocite does not differ in phase appearance from that already described elsewhere, and it seems to retain on cooling less dissolved bismuth than the chalcocite formed in specimens high in sulphur.

SUMMARY.

The following sulphide minerals have been synthesized by melting together in bombs various elements with sulphur:

Chalcocite.
Covellite.

TABLE XII.

IDENTIFICATION GUIDE.*

Interference Colors on Synthetic Minerals as Function of the Time of Exposure to Standard H_2SO_4-CrO_3 Solution Observed with Low-Power Objectives in Air.
Temperature of Bath 18–20° C.

Phases	Duration of Immersion in H_2SO_4–CrO_3 Solution						Remarks
	30 Seconds	1 Minute	2 Minutes	3 Minutes	5 Minutes	10 Minutes	
Arsenic-sulphide glass			Pale brown	Brown	Violet-blue	Blue—second order colors	
Bismuthinite						Pale tan	
Chalcostibite				Pale yellow	Orange	Pale blue	
Enargite	Unchanged						
Famatinite A	Orange to violet	Blue I	To high-order colors				
B		Tan	Pale brown	Brown-violet	Violet-blue	To high-order colors	
C	Unchanged						
Natural orpiment	Unchanged						
Phase "A" cuprobismutite	Tan-cream	Cream-yellow	Yellow-orange	Violet-blue	Pale blue	To high-order colors	Color fades under oil
Phase "B" klaprothite	Pale tan	Tan-cream	Cream-yellow	Orange-violet	Violet-blue	To high-order colors	
Phase "C" wittichenite	Cream-orange	Orange-violet	Blue-green II	To high-order colors			Color does not fade under oil
Phase "M" variety of wittichenite		Tan-brown-yellow	Orange-violet	Blue-pale blue	To high-order colors		
Natural realgar						Light tan	

* As to the use of the Identification Guide see text, p. 57.

TABLE XII—*Continued.*

Phases	Duration of Immersion in H_2SO_4–CrO_3 Solution						Remarks
	30 Seconds	1 Minute	2 Minutes	3 Minutes	5 Minutes	10 Minutes	
Stibnite	Unchanged						
Tennantite I							Films slower than tennantite II
II			Pale tan	Tan-orange	Orange-violet-blue	Pale blue to high-order colors	
Tetrahedrite A	Tan				Blue		
B		Pale yellow-orange	Brownish-yellow	Violet-blue	To high-order colors		Colors not as pure as on famatinite
C	Unchanged						

Famatinite (varieties A, B, C, and arsenical solid-solution believed to be stibioluzonite).
Tetrahedrite (varieties A, B, C).
Chalcostibite.
Stibnite.
Enargite (and antimonial solid-solution believed to be luzonite).
Tennantite (two forms, I and II).
Realgar.
Two arsenic-sulphide glasses.
Bismuthinite.
Cuprobismutite (phase A).
Klaprothite (phase B).
Wittichenite (two allotropic (?) forms: phases C and M).

The optical character and filming behavior of these minerals were ascertained.

Extensive solid-solution effects were observed and studied.

A new formula is proposed for cuprobismutite.

The structural relationships of the various phases were studied

in some detail and a diagram is proposed for a part of the copper-bismuth-sulphur system.

MINERAL DRESSING LABORATORIES,
MONTANA SCHOOL OF MINES,
BUTTE, MONT.,
October 1, 1938.

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DISCUSSION AND COMMUNICATIONS

THE SEVENTH ASSEMBLY, INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS, WASHINGTON, D. C., SEPT. 4–15, 1939.

Sir: Though it may be too formidable a task to expect any individual these days to achieve mastery of more than a modest fraction of the immense stock of knowledge now included in the geological sciences, awareness of progress in geophysical research and some familiarity and understanding of results that are being attained is vital if a respectable professional standing is to be maintained in the modern exacting and competitive world. Indeed, a narrow specialist who is content with his own restricted interests may soon find himself as much out of the main current of scientific progress and as much an amateur as a naturalist of the old school now is. Consequently, the International Union of Geodesy and Geophysics and its representative in our country, the American Geophysical Union, which endeavor to bring together all physical scientists concerned with problems of the earth, are in a strategic position today to render much needed assistance in breaking down barriers between groups who have been too closely bound by the conventional definitions of their fields.

The international meeting in Washington next September devoted to the physics of the earth affords economic geologists an unusual opportunity not primarily to seek enlightenment on their own immediate problems but to come in contact with stimulating work now in progress in a half dozen or more fields that are providing basic data which they even more than others so badly need. In each of the subjects, with which the Assembly will be concerned, (viz. geodesy, seismology, meteorology, terrestrial magnetism and electricity, physical oceanography, volcanology and hydrology) answers are to be found to particular

questions which are engaging the attention of economic geologists. In each of these fields new methods of approach are being developed and new lines of attack revealed that could be used effectively even toward objectives of a different sort. Economic geologists, with the opportunities that commercial work affords them to test their conclusions against the realities of mining or drilling, are becoming more and more exacting with regard to observation and interpretation of field facts; and they in particular should be alert to take full advantage of the wealth of data and ideas that are being accumulated in these subdivisions of science, whose manifold applications to earth problems is the primary concern of the Geophysical Union.

Direct applications of physical devices in structural geology and in oil or ore finding, important as they are in modern economic geology, are, of course, merely one aspect of geophysics. The exhibitions of instruments and opportunities for discussion with technicians in this class of work will undoubtedly be a valuable feature of the September meeting, but even more beneficial to economic geologists will be the new insight and understanding of underlying factors in many of their particular problems which they might well gain from acquaintance with the methods, results, and point of view of the variety of scientists interested in the earth who will be assembled at the meeting.

Although the Society of Economic Geologists is not participating in a formal way in the sessions, the attendance of its members and their contributions, both material and intellectual, toward making the meeting a success will be very welcome.

DONALD H. MCLAUGHLIN.

REVIEWS

Thetford, Disraeli, and eastern half of Warwick Map-areas, Quebec. By H. C. Cooke, with chapters by T. H. Clark. Pp. 160; pl. 1; figs. 26, geol. maps, 4. Can. Geol. Surv. Mem. 211. Ottawa 1937. Price 50 cts.

This region is the heart of Canada's asbestos industry and the center of the important ultrabasic belt in southern Quebec. Memoir 211 contains so thorough descriptions of the region and so many outstanding facts on ultrabasic magmas that it should become a standard reference on these subjects. A bibliography of 135 titles lists most important related works except two recent ones on Scandinavian serpentines. The type is clear and the vocabulary simple. Typographical errors are remarkably few and unimportant although one which gives a dip in the direction of the strike axis (p. 49) causes some confusion.

The surficial rocks of the area are divided into three main age groups. The Caldwell series (Cambrian), the Beauceville series (Ordovician) and the Lake Aylmer series (Devonian) are separated by unconformities of varying magnitude and by periods of intrusion. Boulder conglomerates appear in the two later series and lavas constitute an important part of both early groups. Gabbro sheets and sills spread out below the lavas of the Caldwell series in Cambrian time and seem to have impeded upward intrusion of the late Ordovician peridotites and pyroxenites. This barrier concentrated the ultrabasics on a major northeasterly striking anticline and subsequent erosion of the crest limited their distribution to bands on either side of the axis. The Lake Aylmer series is cut off on the southeast by the Weedon thrust. Granite intrudes rock of all ages.

The peridotite and pyroxenite intrusives form lenses with wallrocks distorted locally to conform with their lenticular outline. The average ratio of olivine to pyroxene for the area is about 2 to 1. Peridotite predominates in outcrops northwest of the major structural axis and pyroxenite prevails on the southeast limb but the two types are interbanded in places and pyroxenite intrudes peridotite at many localities. Deformation of olivine or pyroxene crystals is negligible. Contemporary feldspathic intrusives are almost unknown. Cooke presents evidence to show that,

"The field facts in Thetford district seem to require the conclusion that the peri-

dotites and pyroxenites actually were introduced into their present positions in the liquid form, with much the same compositions as they now possess." (P. 65.)

Their lenticular shape is attributed to thrust of a viscous ultrabasic magma (p. 60) which is interpreted to be a fluid at the time of intrusion (p. 75). Narrow and insignificant metamorphic zones are considered opposed to high magma temperature and excessive emission of water during crystallization.

The asbestos deposits lie around centers near the northwest side of the peridotite belt and occur in crush zones between converging faults. Recast analyses of the asbestos fiber indicate that it is principally serpentine with 15 per cent (34 per cent in brittle Vimy Ridge deposit) of dissolved chlorite, talc, brucite, periclase and silica molecules. The brittle varieties contain more of the chlorite, talc and periclase molecules than the flexible sort and of these talc is considered most significant. Width of the altered wallrock zone varies greatly but is comparatively constant for the same vein and even for the same deposit. Contraction cracks constitute 0.8 per cent of the walls, are widest adjacent to the vein and suggest leaching of vein matter from nearby rock. Fibers are perpendicular to walls in horizontal and vertical veins only. They are free in single and ordinary multiple veins but are frozen to the inside wall in complex ribbon veins. Growth was from the free end when proper thermal conditions existed and solutions and space were provided for crystallization. The asbestos producing solution is considered to be simply water which derived serpentine for the asbestos from the adjacent walls;

"The distribution of deposits from northeast to southwest indicates that there must have been two centers from which such solutions originated, one of which produced the Thetford-Black Lake-Vimy Ridge group of deposits, and the other the Johns-Manville and Nicolet Asbestos deposits, leaving the intervening areas of peridotite barren." (P. 125.)

Asbestos formed where the temperature was at least as high as necessary for magnetite crystallization, and massive serpentine filled the fissures wherever the temperature dropped. The numerous granite intrusives in the two asbestos centers are considered as thermal conditioning agents which raised the temperature to the critical point.

Soapstone deposits of the area seem to have been made by the same solutions that formed the asbestos. They represent a further stage in the transformation. Chromite-bearing masses are divided into original or disseminated bodies and massive or hydrothermal deposits. None are operated at present.

If this reviewer may be allowed to comment he would commend the thorough descriptions and numerous text figures and express regret only

that the latter are too generalized to conform with the detail of descriptions. Geologists may entertain the primary peridotite magma idea with strong reservations but the evidence favors its existence. Individual experiences with this magma type are less worthy than a thorough respect for its capriciousness; whereas the magma seems to have been liquid when it intruded Quebec rocks and crystal alignment is attributed to post-intrusion movement (p. 65), an alignment of olivine crystals in many bodies along its southern extension into Vermont is such as would suggest invasion by a suspension of crystals in a fluid. Cooke has given a masterful presentation of evidence relating to the mode of growth of cross-fiber asbestos; the resultant concept of vein filling adds greatly to our knowledge of details in mechanism of asbestos vein formation but makes no major change from that postulated by Keith. Reasonable doubt remains whether pure water or orthosilicic acid solution is the agent which caused solution of the serpentine. Certainly authors who follow the fissure-filling hypothesis—in contrast to the simple alteration-replacement origin—would agree that both serpentine and water existed in the solution when it began to deposit asbestos and particularly where asbestos fibers abut on fresh olivine walls. The solution that formed fibers in the latter sort of vein could not be simply aqueous but must have been a more complex type that brought serpentine from a more remote source even although it was within the same ultrabasic. Recognition that asbestos bearing districts are principally in areas with granites younger than the ultrabasics and that the commercial deposits are in crush zones within these districts are two significant contributions to knowledge of these unique deposits.

GEO. W. BAIN.

Lexicon de Stratigraphie. Vol. I. **Africa.** Edited by S. H. HAUGHTON. Pp. vi + 432. Cloth 8½ × 5¾. Thos. Murby & Co., London, 1938. Price 31s. 6d. Nordemann Pub. Co., N. Y. Price $9.65.

The first volume of the series of lexicons of stratigraphy projected by the XVth International Geologic Congress in 1929 deals with the stratigraphy of Africa. The Committee in charge of the matter decided to "attempt to produce a Lexicon containing definitions of all unit stratigraphical names that have appeared in geological literature, to subdivide the Lexicon geographically, and to issue one volume for each continent with definitions arranged in alphabetical order."

Each definition, so far as possible, "incorporates the original status of the term defined, the changes that have taken place in its meaning, the present day usage, the geological relationships and geographical distribution within the continent of the term defined, a list of the chief fossils characteristic of the unit, and references to the most important literature."

In the Index are references to 1,265 stratigraphic units. The names of the contributors to the text are a guarantee of its authority.

W. S. BAYLEY.

Manganese. By A. W. GROVES. Pp. 164. Imperial Inst. Min. Resources Dept. London, 1938. Price 3/6.

This is a treatment of the world resources of manganese, with special emphasis on British Empire deposits. The book deals with the ores and minerals of manganese, uses, marketing, distribution, occurrences, production, treatment and resources of manganese. Those of the British Empire are considered under each country, followed by those of all foreign countries that contain manganese ores.

This handy volume is a part of the comprehensive survey of the mineral industry of the British Empire and foreign countries. It is an excellent brief on manganese deposits.

Micropedology. By W. L. KUBIËNA. Pp. xvi + 243. Figs. 132. Cloth, 9 × 6¼. Collegiate Press, Inc., Ames, Iowa, 1938. Price, $3.00.

In the Foreword of this volume the author states that with some changes and additions its contents are essentially the lectures given by him to graduate students at the Iowa State College in 1937. It discusses the fundamental principles of microscopic pedology, which is not much further developed today than was petrography in the middle of the last century.

The main part of the book is divided into four topics, viz: (2) The technique of micropedology, (3) soil fabrics and (4) biological soil microscopy.

Under (2) are given descriptions of special types of petrographic microscopes and such accessories as are specially adapted to soil studies, and in addition directions for the optical and chemical methods for determining the composition of soil components, and directions for soil sampling and the preparation of soil samples for study. Part (3) is the characteristic feature of the volume. It is a discussion of soil fabrics under the headings elementary fabrics, fabrics of aggregates and fabric types, with illustrations of each.

The part (4) deals with the activity of living things in the soil as observable under the microscope. "The subject and unit of observation is the microhabitat together with its conditions, the association of organisms found in it, as well as the particular morphology and activity of the organisms as influenced by its conditions." It includes "also the microscopic study of the life parts of higher plants, such as plant rootlets."

The book is clearly written and well printed, and the illustrations are abundant and well chosen.

W. S. BAYLEY.

Mineral Valuations of the Future. By C. K. LEITH. Pp. 116. Amer. Inst. Min. and Met. Engrs. Series. New York, 1938. Price $1.50 and $1.00.

Another publication of the Seeley W. Mudd Fund. It deals with the "Significance of Mineral Values;" "New Conditions affecting Mineral Values" such as nationalization, conservation, taxation and advanced technology; "Methods of Mineral Valuation" comprising all of the customary methods; "Tonnage Estimates;" "Future Annual Production," life, costs, selling prices, profits, rate of returns, scarcity value, and "Conclusions as to Future Trends of Minerals." It is a well written book and of interest to geologists, mining engineers, mineral economists, bankers and tax officials.

Geology and Mineral Resources of the Honeybrook and Phoenixville Quadrangles, Penn. By F. BASCOM AND G. W. STOSE. Pp. 145; Figs. 20. U. S. Geol. Surv. Bull. 891. Washington, 1938. Price 65 cts.

This Bulletin represents the results of a careful piece of areal work by competent investigators in a region where differences of opinion have existed regarding the geomorphology, stratigraphy and structure. The Pre-Cambrian Pickering gneiss, Franklin limestone and Wissahickon formations and the numerous igneous rocks of the same age are described, as are Cambrian, Ordovician and Triassic formations. Of particular interest is the interpretation of structure. The mineral resources include miscellaneous non-metallics, magnetite and limonite ore; lead, zinc and copper deposits of minor importance; and important graphite deposits.

BOOKS RECEIVED.

J. D. BATEMAN.

Orders for official publications and for single copies of journals should be sent direct to their publishers and not to ECONOMIC GEOLOGY.

Rice Lake Gold Area, Southeastern Manitoba. C. H. STOCKWELL. Pp. 79; figs. 5; pls. 3; geol. maps, 8. Geol. Surv. Can., Mem. 210. Price, 25 cts. *Unconformable post-instrusive San Antonio formation contributed to stratigraphy; geology of San Antonio Gold Mine.*

Geology and Mineral Deposits of Freegold Mountain, Carmacks District, Yukon. J. R. JOHNSTON. Pp. 21; geol. map. Geol. Surv. Can., Mem. 214, 1937. Price, 10 cts. *Gold in magnetite and quartz veins.*

Laberge Map-Area, Yukon. H. S. BOSTOCK AND E. J. LEES. Pp. 32; pls. 3; geol. map. Geol. Surv. Can., Mem. 217, 1938. Price, 25 cts. *Placer and lode gold.*

Sand and Gravel Resources of Verchères, Saint-Hyacinthe, Bagot and Adjacent Counties, with Particular Attention to Moulding Sand. H. W. MCGERRIGLE. Pp. 53; figs. 8; map. Quebec Bur. Mines, Ann. Rept., pt. E, 1936. Quebec City, 1937.

Quality of Water of the Rio Grande Basin above Fort Quitman, Texas. C. S. SCOFIELD. Pp. 294. U. S. Geol. Surv., W–S Paper 839, 1938. Price, 30 cts. *Statistical.*

Geology of the Slana-Tok District, Alaska. F. H. MOFFIT. Pp. 54; figs. 4; pls. 3; geol. map. U. S. Geol. Surv. Bull. 904, 1938. Price, 35 cts. *Pre-Devonian to Mesozoic.*

Inventory of Unpublished Hydrologic Data. W. T. HOLLAND AND C. S. JARVIS. Pp. 77. U. S. Geol. Surv. W–S Paper 837, 1938. Price, 15 cts. *Statistical.*

Labor del Departamento de Mineria Aurifera. J. F. A. REVOREDO. Pp. 325. Cuerpo de Ingenieros de Minas del Peru, Bol. 121. Lima, 1938. *Metallurgical investigations of gold ores.*

La Métallogenèse Magmatique et Recherches Sélénogiques. C. L. SAGUI. Pp. 22; fig. Inst. de Fisiog. y Geol., Argentina. Rosario, 1938. *Transmutations of elements ascribed to pressures within the earth.*

Spirit Leveling in Missouri, 1896–1937. Pt. 2, Bull. 898–B; pp. 165; price, 30 cts.; south-central Missouri. Pt. 2, Bull. 898–C; pp. 142; price, 25 cts.; east-central Missouri. J. G. STAACK. U. S. Geol. Surv., 1938.

The Brown Iron Ores of Eastern Texas. E. B. ECKEL. Pp. 157; figs. 6; pls. 17; maps, 3. U. S. Geol. Surv. Bull. 902, 1938. Price, $1.00. *Available high-grade Tertiary iron ores estimated from 150,000,000 to 200,000,000 tons.*

Report of the Geological Survey Branch, Department of Scientific and Industrial Research, New Zealand, 1937–1938. Pp. 22. Wellington, 1938. *Summary reports of field studies.*

Igneous Geology and Structure of the Mount Taylor Volcanic Field, New Mexico. C. B. HUNT. Pp. 30; figs. 13; pls. 12; map. U. S. Geol. Surv. Prof. Paper 189–B, 1938. Price, 45 cts. *Miocene to Pliocene volcanics.*

Experiments in Geophysical Survey in New Zealand. N. MODRINIAK AND E. MARSDEN. Pp. 92; maps, 30. N. Z. Dept. of Sci. and Indust. Research, Geol. Mem. 4, Wellington, 1938. Price, 7/6. *Results of application of different methods to structural problems.*

Report of the Committee on the Measurement of Geologic Time, 1937–1938. A. C. LANE (chairman). Pp. 123. Nat. Research Council, Washington, Oct., 1938. *Brings previous reports up to date.*

The San Juan Country. H. E. GREGORY. Pp. 123; figs. 4; pls. 26. U. S. Geol. Surv. Prof. Paper 188, 1938. Price, 60 cts. *A geographical and geological reconnaissance of southeastern Utah.*

A New Upper Cretaceous Rudistid from the Kemp Clay of Texas. L. W. STEPHENSON. Pp. 15; pls. 5. U. S. Geol. Surv. Prof. Paper 193–A, 1938. Price, 25 cts.

Stripa Odalfälts Geologi. PER GEIJER. Pp. 42; figs. 21. Sveriges Geol. Undersönk., No. 28, Stockholm, 1938. Price, 6 kron. *Study of iron ore deposits in the Stripa mining field that are similar to the Lake Superior type of pre-Cambrian iron formation.*

Federal Placer Mining Laws and Regulations. F. W. JOHNSON. **Small Scale Placer Mining Methods.** C. F. JACKSON. Pp. 49; figs. 26. U. S. Bur. Mines Tech. Paper 591, 1938. Price, 10 cts. *An informative booklet.*

Carbonizing Properties of West Virginia Coals from the Alma, Cedar Grove, Dorothy, Powellton A, Eagle, Pocahontas and Beckley Beds. A. C. FIELDNER, J. D. DAVIS, W. A. SELVIG, R. THIESSEN, D. A. REYNOLDS, C. R. HOLMES AND G. C. SPRUNK. Pp. 162; figs. 129. U. S. Bur. Mines Bull. 411, 1938. Price, 30 cts.

Studies of Certain Properties of Oil Shale and Shale Coal. B. GUTHRIE. Pp. 159; figs. 29. U. S. Bur. Mines Bull. 415, 1938. Price, 25 cts.

Analyses of Rocks, Minerals, Ores, Coal, Soils and Waters from Southern Africa. A. L. HALL. Pp. 868. Union of South Af. Geol. Surv. Mem. 32, Pretoria, 1938. Price, 15/–. *Contains 5,983 analyses made to the beginning of 1936.*

Flow of Air and Natural Gas Through Porous Media. T. W. JOHNSON AND D. B. TALIAFERRO. Pp. 55; figs. 16. U. S. Bur. Mines, Tech. Paper 592, 1938. Price, 10 cts.

St. George's Coalfield, Newfoundland. A. M. BRYAN. Pp. 23; figs. 9. Nfld. Geol. Surv., Informat. Circ. 5, St. John's, 1938. *Coal cannot be economically extracted, although there is a large tonnage present.*

The Geology of the Country around the Jumbo Mine, Mazoe District, Southern Rhodesia. J. C. FERGUSON AND T. H. WILSON. Pp. 137; pls. 7; geol. map. South. Rhod. Geol. Surv. Bull. 33, Salisbury, 1937. Price, 4/9. *Gold deposits in pre-Cambrian complex.*

Geophysical Abstracts 92, January–March, 1938. W. AYVAZOGLOU. Pp. 50. U. S. Geol. Surv. Bull. 909–A, 1938. Price, 10 cts. *Brings Bulletins 895 A–D up to date.*

Bulletin du Service des Mines, No. 1. Gouvernement Général de L'Afrique Occidentale Française. Grande Imprimerie Africaine. Dakar, 1938. *Notes on hydrology, geology, salines, titanium and chromite of French West Africa.*

Rapport sur l'Industrie Minérale, 1937. M. P. SEYER. Gouver. Général de L'Afrique Occidentale Française. *Mineral statistics relating to Soudan, Guinea and Ivory Coast in French West Africa. Production in 1937 was valued at 103,050,000 francs, of which 100,050,000 francs was represented by gold.*

SCIENTIFIC NOTES AND NEWS

E. C. HARDER, at present in Calcutta, India, expects to return to Montreal the latter part of March.

T. WAYLAND VAUGHAN, senior geologist of the U. S. G. S., has been elected president of the Geological Society of America.

N. H. DARTON has continued his studies of the structure of the Atlantic Coastal Plain on a grant from the Penrose fund. A report on gravel and sand of eastern Maryland and a structure map of the northern anthracite coal basin are being published by the U. S. G. S. Some recent work has included investigations of foundations and dam sites and certain problems connected with litigation in the potash fields of New Mexico.

C. O. HUTTON, who has been doing research work at Cambridge, has been appointed petrologist to the New Zealand Geological Survey.

R. J. PARKER of the Rhodesian Selection Trust has been appointed managing director of Consolidated African Selection Trust which operates the Gold Coast mines.

J. T. SINGEWALD has been elected treasurer of the Society of Economic Geologists succeeding W. B. Heroy.

G. D. LOUDERBACK has been elected vice president of the Society of Economic Geologists, succeeding E. S. Moore, who became president upon the death of A. C. Veatch, president-elect.

The ANNOTATED BIBLIOGRAPHY OF ECONOMIC GEOLOGY has now in press a consolidated index of the first ten volumes, which may be obtained for $5.00 from W. S. Bayley, Urbana, Ill.

EMMONS MEMORIAL FELLOWSHIP

The Emmons Memorial Fellowship in Economic Geology is available for this year (stipend $1200). Applications and accompanying testimonials should be submitted not later than April 15. Applicants should be qualified by training and experience to investigate some problem in economic geology and should submit a definite statement of their problem to the Committee, under whose oversight the work will be undertaken at any institution approved by them. The Fellow must give his entire time to the problem, which may be used for a doctorate dissertation. Application blanks and further information may be obtained from Alan M. Bateman, Charles P. Berkey, Waldemar Lindgren, or the Secretary, Columbia University.